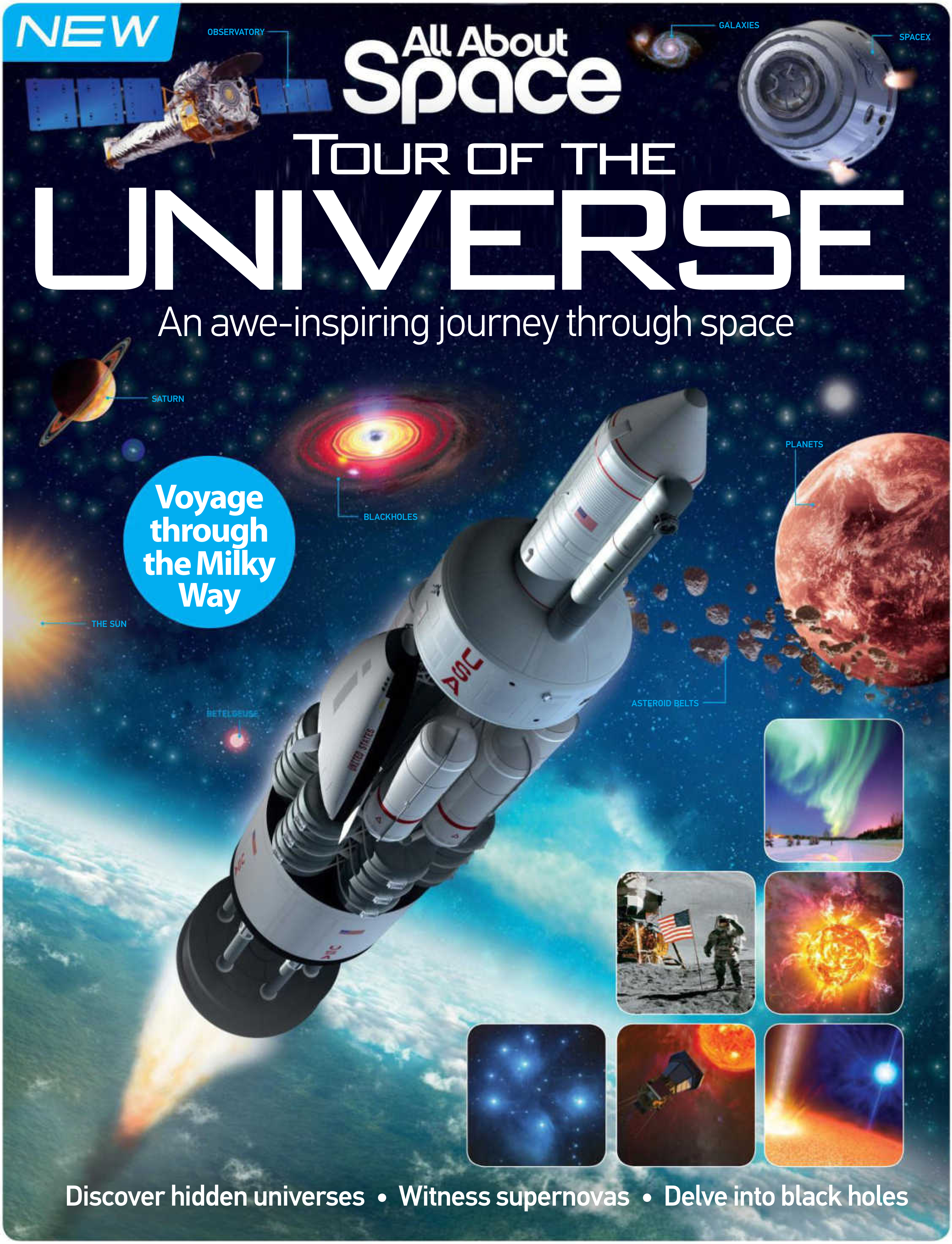
NEW

All About Space

TOUR OF THE UNIVERSE

An awe-inspiring journey through space

Voyage through the Milky Way



Discover hidden universes • Witness supernovas • Delve into black holes

Welcome to the

All About Space

Tour of the Universe

When Neil Armstrong stepped onto the surface of the Moon he declared that it was "One small step for man, one giant leap for mankind." Join us as we step further than you have ever imagined - beyond our Solar System and out into deep space. Journey through our home galaxy, explore our neighbour planets and discover the brutal force of our central star. You will find out all about the ongoing search for extra terrestrial life, and discover how humanity might manage to relocate to Titan in the future. There are so many incredible known phenomena in our universe, and you'll find the greatest and most awe-inspiring here. In this new edition, explore everything from the Milky Way and mega storms to Moon dust and holographic universes. Turn the page and prepare to be astonished by the wonders of the universe we live in.

Tour of the Universe

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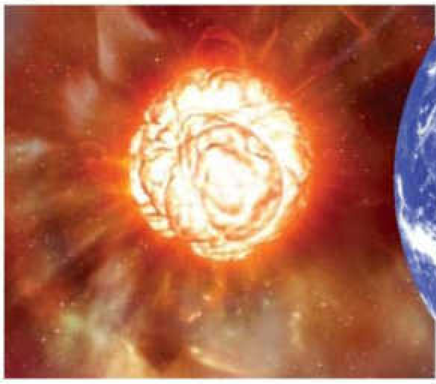
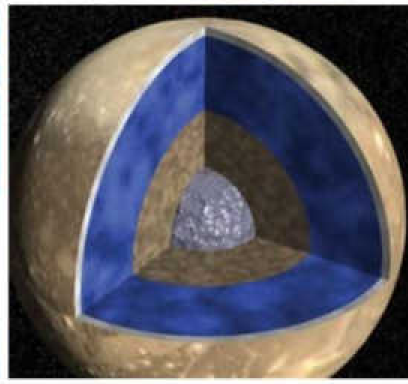






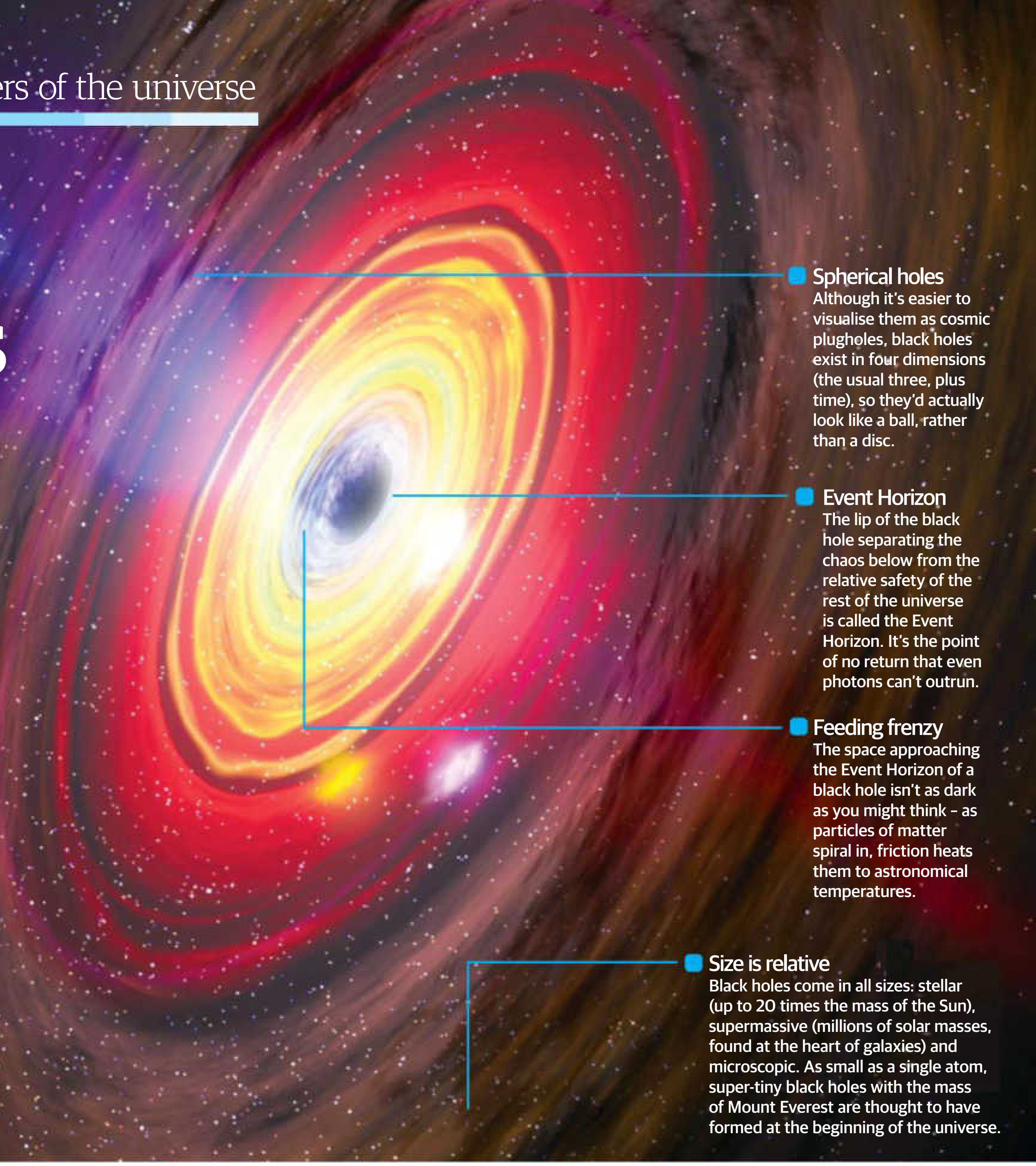

Discover the Wonders of the Universe

From exploring our Solar System to the mysteries of deep space, find out what makes our universe so amazing


What is a black hole?

All sorts of weird and wonderful things can happen when a star dies, such as neutron stars and white dwarfs. Undoubtedly the weirdest of them all, however, are the birth of stellar black holes. Like all the best enigmas of the universe, black holes are as misunderstood as they are mysterious and as hard to observe as they are to comprehend.

Stellar black holes are most commonly formed from the remnants of particularly massive stars when they die – their cores collapsing with a staggering force that defies our understanding of the laws of physics. As the star's mass is forced into an ever-smaller space, the gravitational forces involved effectively rips a hole in the fabric of the universe creating a singularity – the point at which all calculations break down, resulting in infinite loop instead of a number. The end result? The total and utter annihilation of matter and an 'ERROR' screen on the physicist's calculator.



Spherical holes
Although it's easier to visualise them as cosmic plugholes, black holes exist in four dimensions (the usual three, plus time), so they'd actually look like a ball, rather than a disc.

Event Horizon
The lip of the black hole separating the chaos below from the relative safety of the rest of the universe is called the Event Horizon. It's the point of no return that even photons can't outrun.

Feeding frenzy
The space approaching the Event Horizon of a black hole isn't as dark as you might think – as particles of matter spiral in, friction heats them to astronomical temperatures.

Size is relative
Black holes come in all sizes: stellar (up to 20 times the mass of the Sun), supermassive (millions of solar masses, found at the heart of galaxies) and microscopic. As small as a single atom, super-tiny black holes with the mass of Mount Everest are thought to have formed at the beginning of the universe.

How the universe will end

Without the theory of the Big Bang we wouldn't have much to go on when it comes to estimating what the fate of the universe may be. Thankfully, we can come up with several theories for how the universe might end based on our observations of the cosmos, namely that it appears to be expanding at an accelerating rate, but some theories suggest this won't be the case forever.

For example, the False Vacuum theory states that a so-called 'metastability event' could cause the vacuum of space to 'ping' into a lower energy state changing the rules of space, time and matter. If this is the case the entire universe could end at any moment.

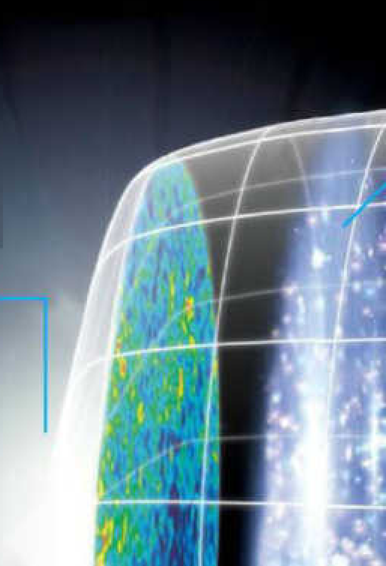
Other popular views on when and how the universe will end include the Big Crunch, which is the theory that the universe will eventually start shrinking back to a singularity and re-spawn a new universe, possibly signifying the endless cycle of our universe's life and death.

There is also the Big Rip theory, where the expansion of the universe would continue to accelerate at such a rate that all the matter would be forcibly ripped apart at the seams.

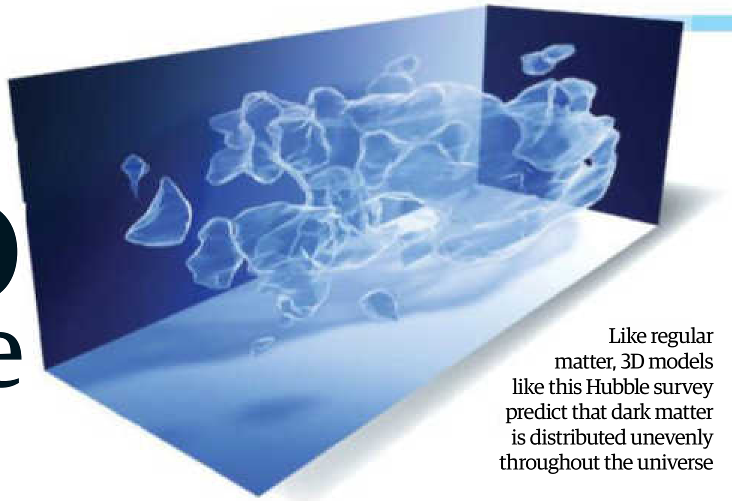
However, the most popular of all current theories is the Big Freeze, which simply dictates that the expansion – and cooling – of the universe will continue unabated until everything in it reaches 'absolute zero'. At this point the universe would cease to move and would become stable, possibly existing forever.

Either that, or our universe could actually be a multiverse and every other possible end to the universe could quite feasibly be happening right now. Since a multiverse of infinite 'verses' would require infinite space and energy, the multiverse would never cease to exist.

Start: The Big Bang
During the first 10-32 seconds following the Big Bang, tiny quantum fluctuations ballooned into a size where they would have been visible to the human eye.



96% of universe is missing



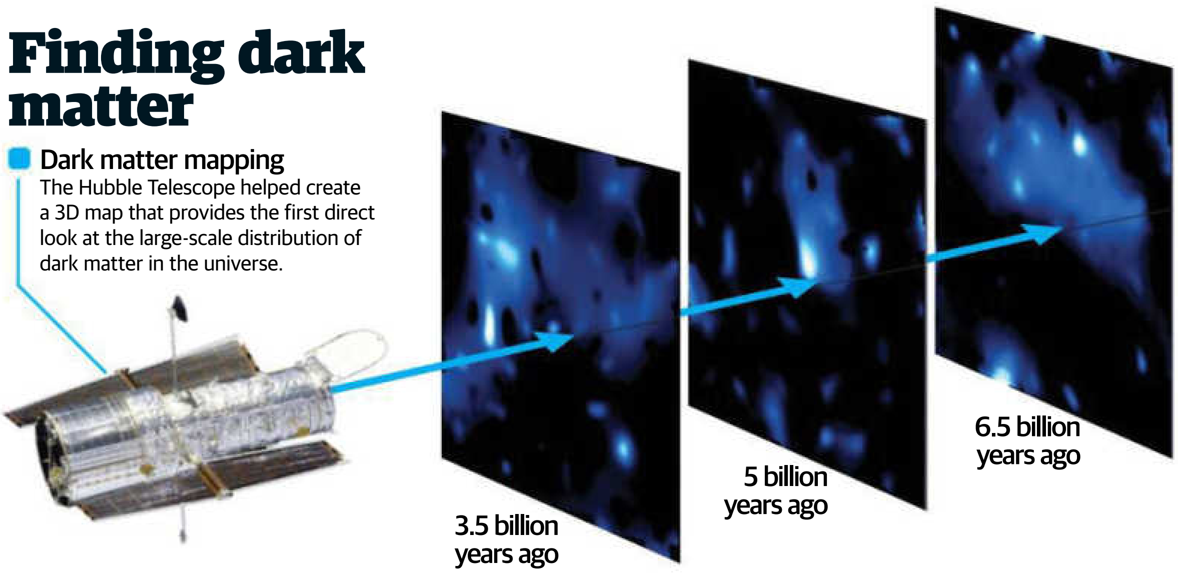
Like regular matter, 3D models like this Hubble survey predict that dark matter is distributed unevenly throughout the universe

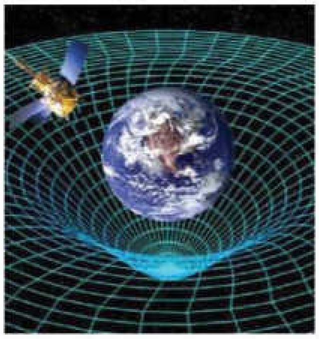
The chilling discovery came to light in the Nineties when astronomers realised the universe's expansion was accelerating instead of slowing, as they'd predicted.

So little is currently known about the mystery, the term 'dark matter' effectively exists as a placeholder – a means to explain an unfathomable problem in a barely more comprehensible way. Thanks to more recent discoveries we do at least have a rough idea of where dark matter resides.

The globular image above depicts the distribution of dark matter across the universe. The COSMOS survey, a Hubble project studying the relationship between large scale structure (LSS) in the universe and dark matter, as well as the formation of galaxies – has offered the most compelling evidence yet that known matter tends to cohabit the same space as the densest concentrations of dark matter. Just don't ask anyone what it is...

Finding dark matter

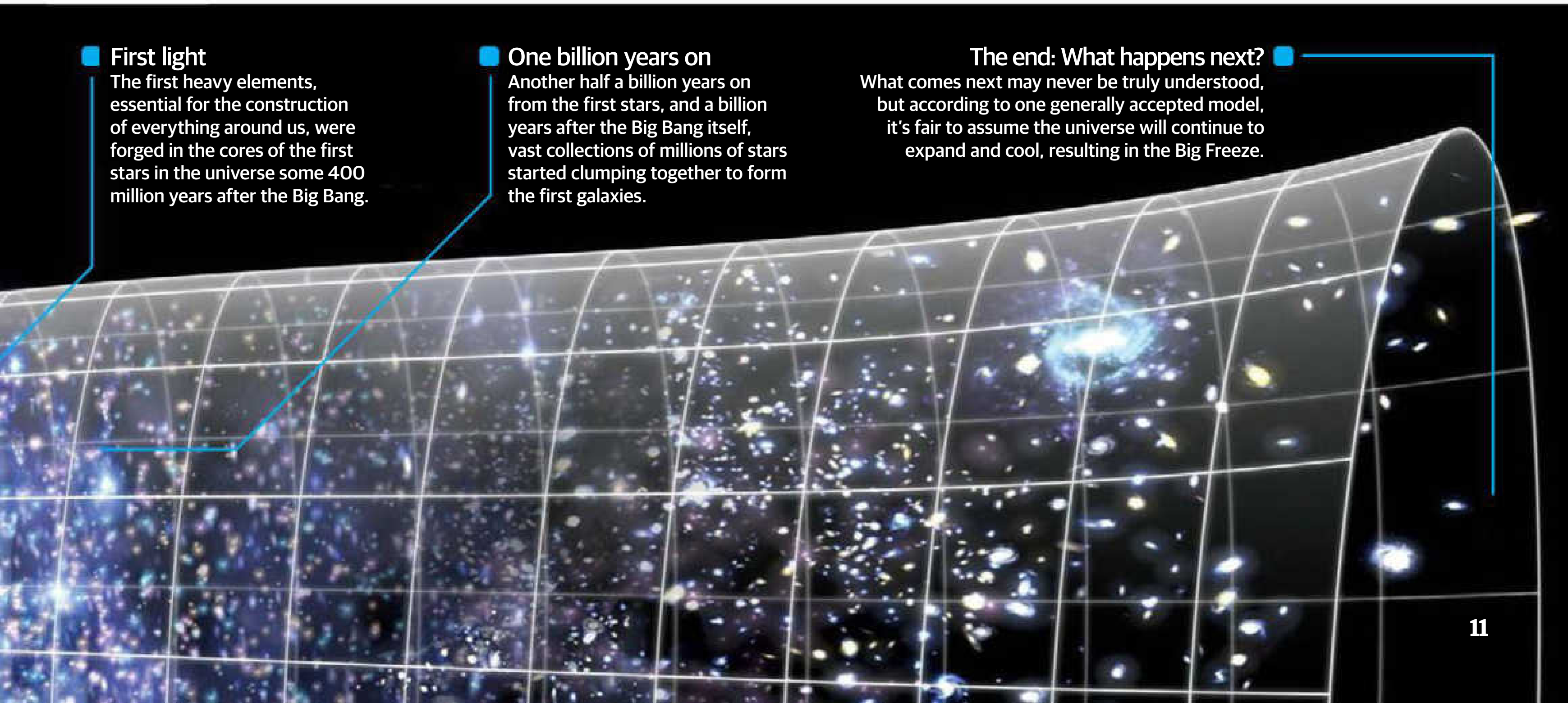




Gravity cannot be explained

Gravity is a mind-boggling conundrum. Despite being able to predict its effect with enough scientific accuracy to chart the locations of celestial bodies millions of years into the future, we haven't yet entirely grasped what makes it work.

We know that gravity operates at the speed of light and attracts clumps of matter with a force directly proportional to their mass and is unlike the other three forces of nature, because it has a fundamental relationship with time and space. What we don't know is what particles are actually responsible for creating the force of gravity. Researchers at particle accelerators on Earth like the Large Hadron Collider near Geneva, Switzerland are hoping to find the answer soon.



Mining asteroids

James Cameron and Google's Eric Schmidt and Larry Page establish the first asteroid-mining company

If successful, Planetary Resources could send robotic mining vehicles to asteroids

It might sound and look like something out of a sci-fi film, but asteroid mining is very much a reality, and one that could greatly benefit humanity. For decades it has been nothing but a pipe dream and, until recently, nobody had been able to devise a clear plan for long-term mining of an asteroid.

That all changed when a new company called Planetary Resources, Inc outlined a clear goal in early 2012 to mine near-Earth asteroids for valuable minerals. Set up by some familiar and rich names, including James Cameron and Google's Eric Schmidt and Larry Page, the company aims to supplement the Earth's natural resources by developing and deploying robotic asteroid-mining vehicles.

Right now, Planetary Resources is still in its very early planning stages, attempting to identify the key technologies that will allow it to produce the necessary machinery to forge these large mining droids. However, the ultimate aim – and one in which its backers readily accept is still a number of decades away – is to survey numerous asteroids for their mineral and water content, before dispatching automated miners to harvest them. Indeed, the existence of Planetary Resources is fascinating because it is in it for the long haul, creating a completely conceivable roadmap to asset extraction. If successful, the endeavour could prove very profitable for the company, with studies indicating that most asteroids are rich in minerals such as iron, nickel and titanium – which are in restrictive supply on Earth. If these elements could be extracted and processed it would prove invaluable for future industry.

> "The aim is to survey asteroids for mineral and water content before dispatching automated miners"

Small, water-rich, near-Earth asteroids could be captured allowing their resources to be extracted

What is most fascinating, though, is that in its mission to mine asteroids, Planetary Resources could actually provide a viable base from which humans could expand into the Solar System. If water, oxygen and construction materials can be acquired from off-planet sources, then the speed and quantity of any planned colonisation project would be dramatically increased.

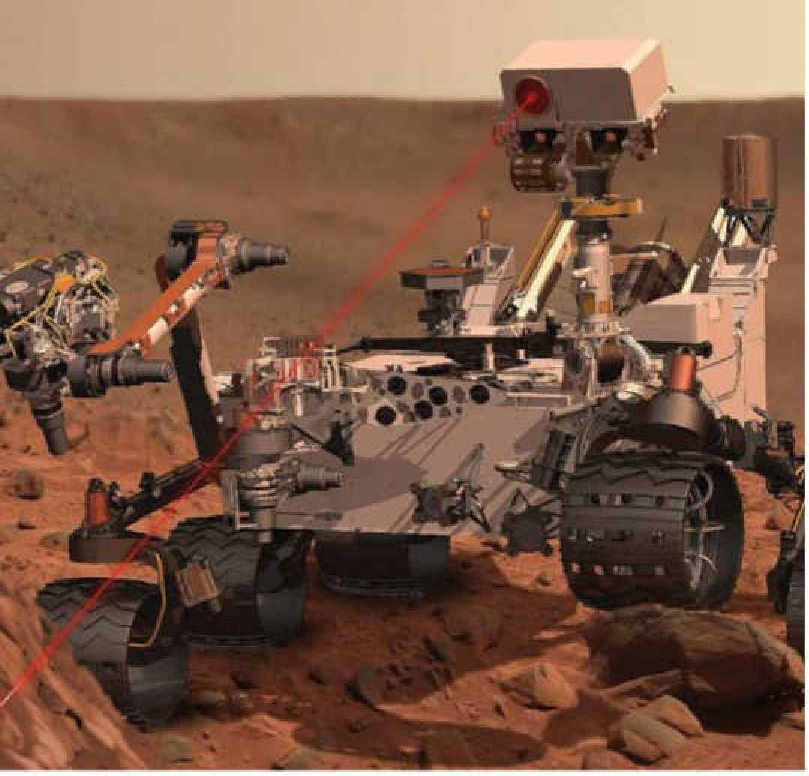
Who's involved?

Eric Schmidt
Schmidt is the executive chairman of Google. He is also a celebrated software engineer.

Larry Page
Page is the CEO of Google and also its co-founder. He specialises in computer science.

James Cameron
Director of *Aliens* and *Terminator 2*, Cameron also helped build the Deepsea Challenger.

Peter Diamandis
Diamandis is a space-flight entrepreneur and expert in designing space vehicles.



Firing lasers on Mars

The Science Laboratory mission to land the Curiosity rover on Mars blasted off on 26 November 2011 and is a simply phenomenal project. Once it has parachuted down to Mars, the state-of-the-art vehicle has only one purpose – to help assess the habitability of the Red Planet. It will do this by performing various tests in its onboard laboratory, including large-scale chemical analysis of its rocky surface, using a ChemCam laser to vapourise pieces of the terrain for more effective study.

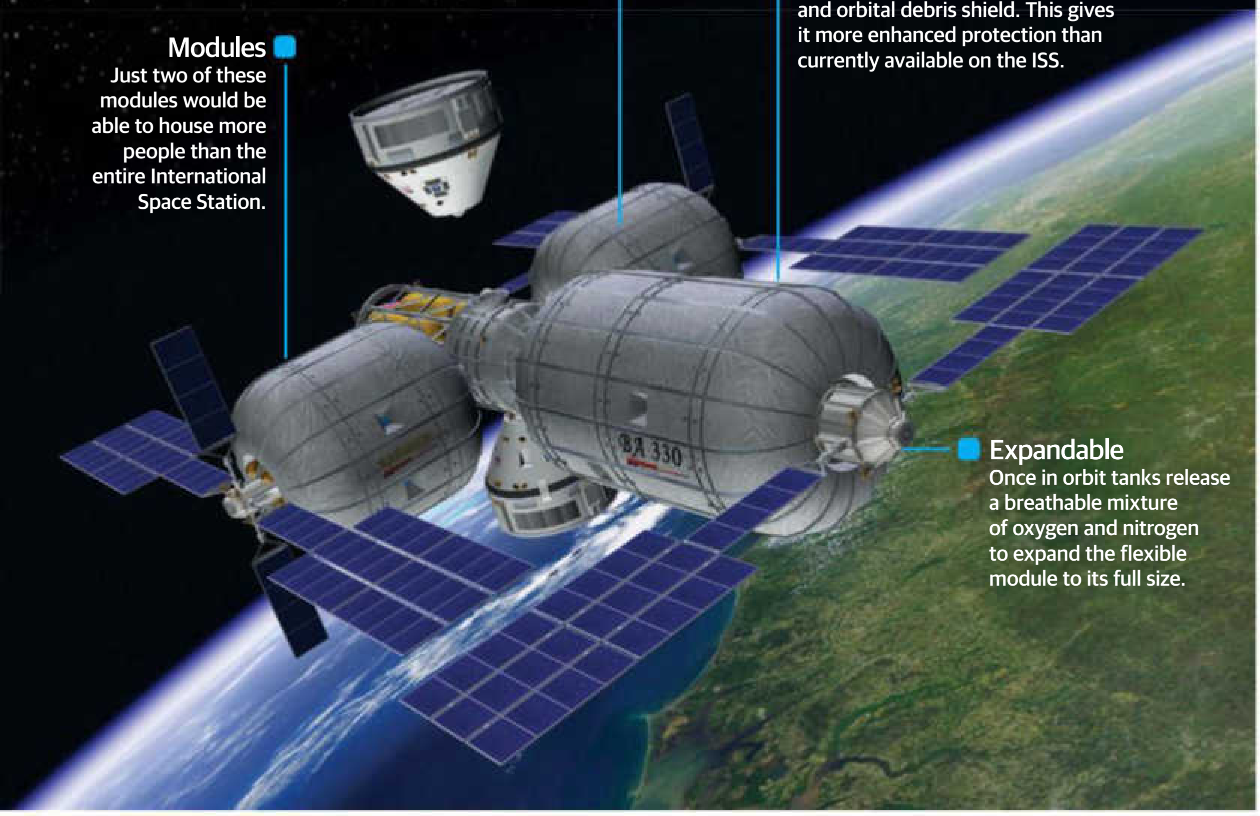
Inflatable space stations

Bigelow Aerospace's inflatable Sundancer space complex is a glimpse into the future of commercial space habitation, laying the groundwork for the BA 330, the first model of its kind to go into production. Launching in a compacted state the Sundancer will expand once it enters orbit. It has been designed with space tourism in mind and, if all goes to plan, could be offering stay-overs within the next decade.

Strong material
The expandable body is fabricated from numerous layers of Kevlar-like materials, providing a high resistance threshold and strength to support a large observation window.

Debris shield
The Sundancer has a micrometeoroid and orbital debris shield. This gives it more enhanced protection than currently available on the ISS.

Modules
Just two of these modules would be able to house more people than the entire International Space Station.



Expandable
Once in orbit tanks release a breathable mixture of oxygen and nitrogen to expand the flexible module to its full size.

Book a flight to the ISS

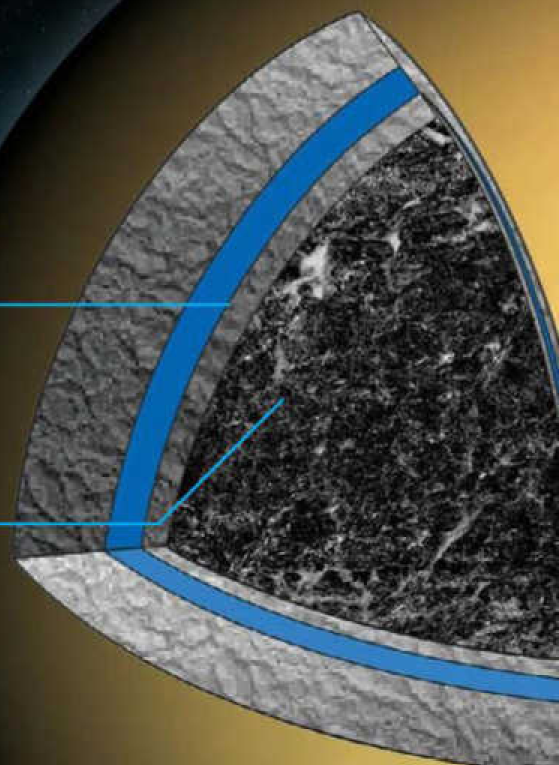
SpaceX's Dragon spacecraft is exciting for all the right reasons. As discussed earlier (see page 12) it has already begun cargo missions to the International Space Station, and in the next few years it is set to begin manned expeditions to space, the first private spacecraft ever to do so. It has already received funding from NASA under the Commercial Crew Development programme, and by 2015 at the earliest it is expected to start ferrying up to seven astronauts on each flight to Earth orbit.

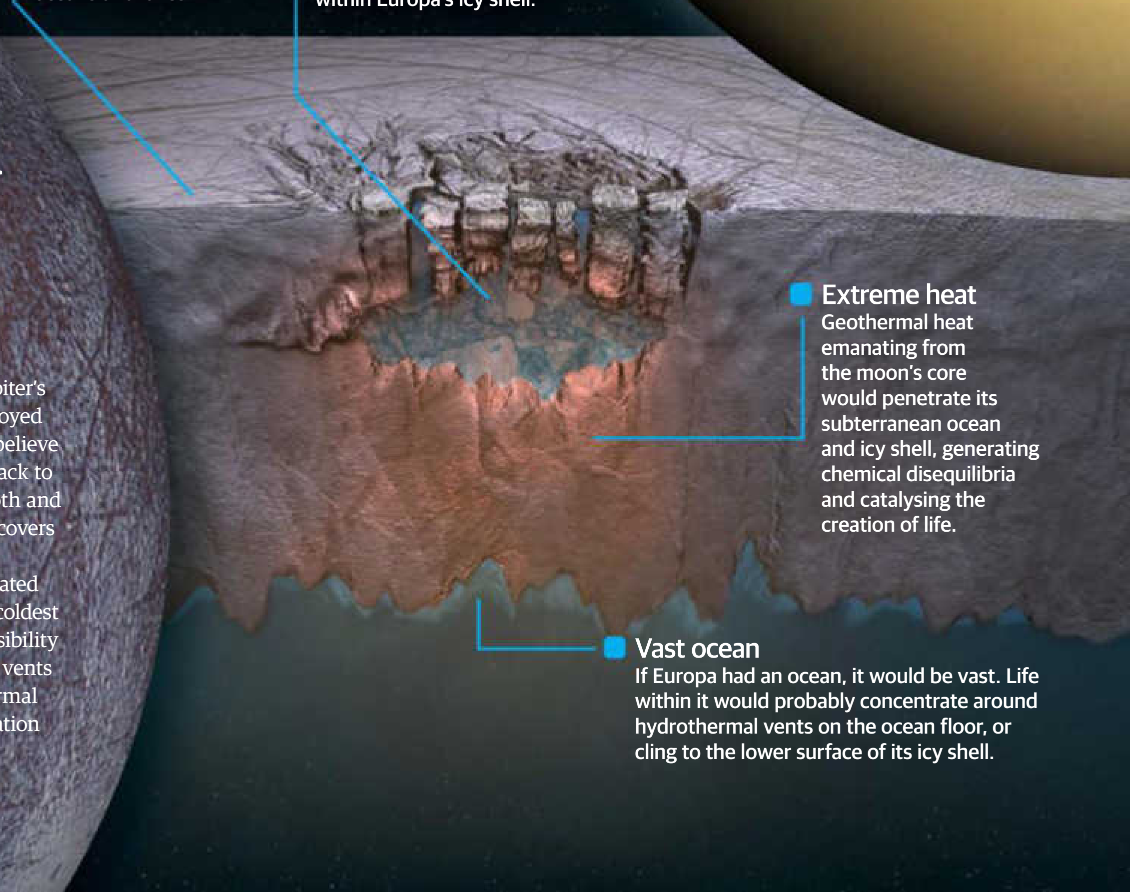
First visit to Pluto

Currently en route to the dwarf planet Pluto, NASA's New Horizons spacecraft holds the record for the highest-velocity ejection speed from Earth's atmosphere of any human-made object. It was fired directly into an Earth-and-solar escape trajectory with the equivalent speed of 58,536 kilometres per hour (36,373 miles per hour)! Upon reaching Pluto in 2015 it will complete the first-ever flybys of the super-cold planet and its moons – Charon, Nix and Hydra – analysing them and their environment with its seven on-board sensors.

Discovering life on Jupiter

The JUICE spacecraft (Jupiter Icy Moon Explorer) - is arguably the most exciting development yet in the search for alien life. The European Space Agency spacecraft, which was selected above a host of rivals for the crucial mission, is due to head to the Jupiter system in 2022 in search of new life forms. Launching on the back of the extremely powerful Ariane 5 rocket, JUICE will engage its solar-powered electric engines and make the long-haul, eight-year flight to Jupiter. Upon arriving, JUICE will analyse the planet, as well as its icy moons Europa, Callisto and - most importantly - Ganymede. Ganymede will be the focus of its 1.4GB daily data downlink as reports indicate that it contains a subsurface ocean. If this is true, then that ocean could be the location of our very first contact with an alien organism.





Underground oceans of Europa

While primarily being sent to search for alien life on Jupiter's moon Ganymede, the JUICE spacecraft will also be deployed to Europa. The reason? Scientists at NASA and the ESA believe it could also harbour life. Indeed every report beamed back to Earth to date has indicated that due to the moon's smooth and youthful surface, there is an excellent possibility that it covers a vast subterranean ocean.

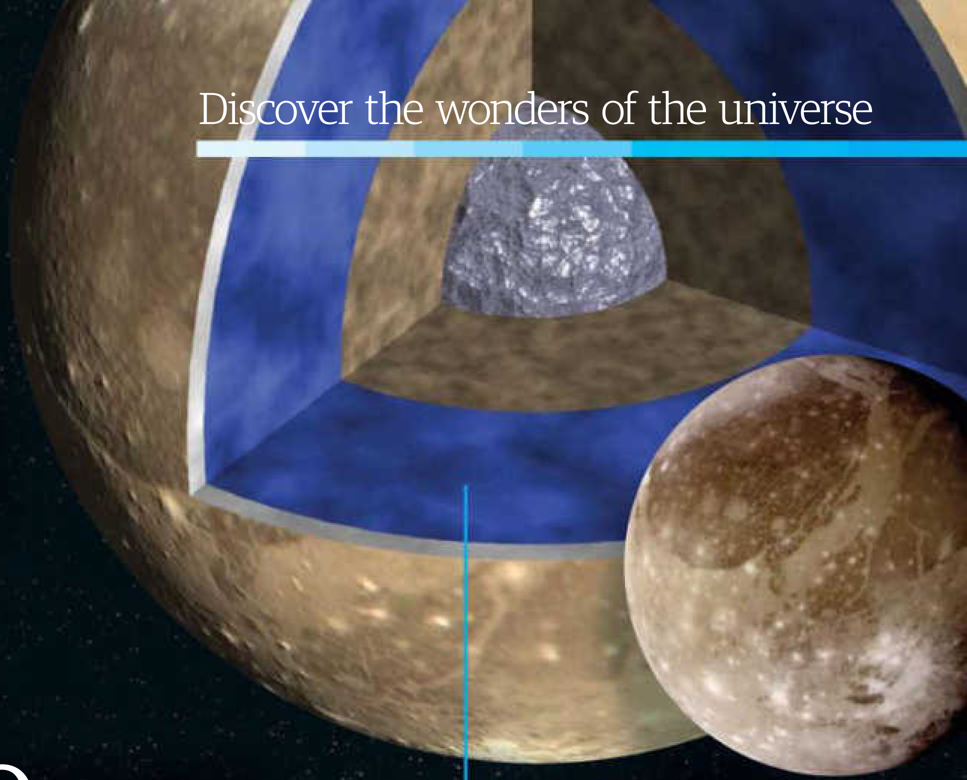
If there is an ocean under Europa, then - as demonstrated in missions down to the bottom of Earth's deepest and coldest oceans, where microbial life is abundant - there is a possibility that some form of life could exist as deep hydrothermal vents emanating up from the moon's core could inject geothermal energy into the waters, providing the catalyst to the creation of life.

Earth-like surface
Titan's surface is Earth-like, with rivers and lakes of liquid ethane and/or methane potentially providing habitats for non-water-based life forms.

Atmosphere
Much like its surface, Titan's atmosphere is also very Earth-like. It is dense, chemically active and is privy to weather such as cloud formations and rain.

Titan's Earth-like climate

Saturn's moon Titan is incredibly interesting because it has a dense nitrogen-rich atmosphere and a climate similar to that on Earth, with wind, rain and clouds a frequent occurrence. Indeed, its surface even has similar features, too, such as sand dunes, rivers, lakes and seas – although the latter's 'water' is most likely liquid methane and ethane. As such, it is thought by scientists to potentially be a habitat in which microbial extraterrestrial life could survive, or at the very least, act as a rich prebiotic environment for their future creation.



Going deeper
Ganymede has a cold rigid ice crust, an outer warm ice mantle, an inner silicate mantle and a metallic core.

Oxygen on Ganymede

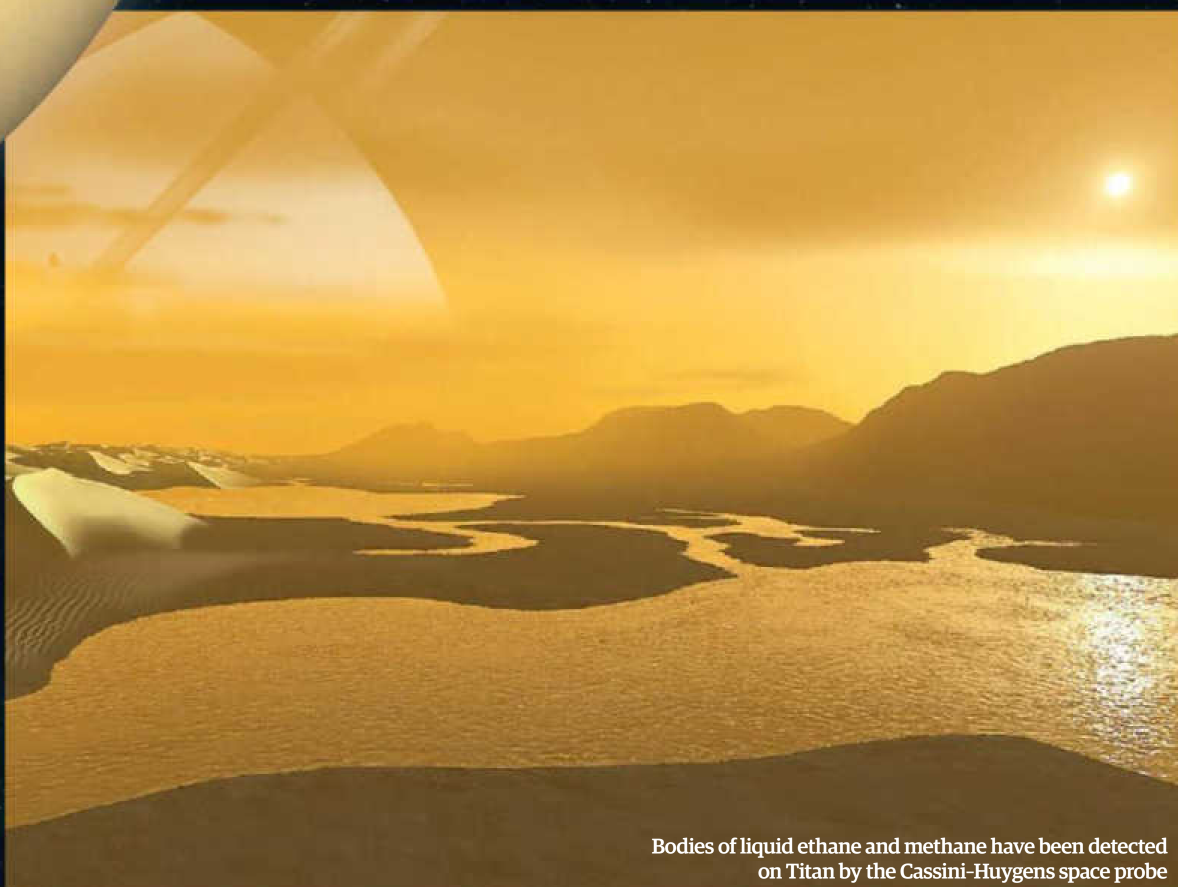
Reports indicate that oxygen may exist within the atmosphere of Jupiter's Ganymede moon. The oxygen is created when water ice on the moon's surface is split into hydrogen and oxygen by impacting radiation waves, with the hydrogen then proceeding to be lost from the atmosphere quicker than the oxygen due to its low atomic mass. This process leaves a thin layer that includes oxygen, oxygen gas and ozone. Importantly, however, the presence of oxygen is not direct evidence that there could be life on Ganymede, rather just an extra layer of chemical complexity in which life could, theoretically, be generated. However, the oxygen concentrations on Ganymede are roughly equivalent to those found on Mars, a planet on which scientists believe life could have existed at one time.

Life in the methane lakes?

One of the best chances of finding life on Titan is within its numerous, large methane lakes. These lakes, which litter the moon's surface, could act as our water-based ones do on Earth.

Critically, however, for this to be possible it would require the alien organism to intake hydrogen rather than oxygen, react it with acetylene instead of glucose and produce methane instead of carbon dioxide.

While sounding far-fetched, it becomes more of a reality when you consider that there are various methanogens (methane-producing microorganisms) on Earth that obtain their energy by reacting hydrogen with carbon dioxide in a very similar way.



Bodies of liquid ethane and methane have been detected on Titan by the Cassini-Huygens space probe

Discovering new Earths

Scientists are busy in their search for new, Earth-like planets outside of our Solar System and new advances in technology may help us find one soon

Planet hunting is a new and exciting area of astronomy barely two decades old that, thanks to missions such as NASA's Kepler telescope, is revealing more and more data about intriguing new worlds outside of our Solar System, known as extrasolar planets or exoplanets. Only in the last 20 years has sufficient technology been available to allow us to categorically prove the existence of these planets. While we're still some way off seeing detailed imagery of direct exoplanet observations, projects like NASA's James Webb Space Telescope and the European Extremely Large Telescope (E-ELT) will bring Earth-size exoplanets into view and even study the composition of their atmospheres.

The number of bizarre and familiar new worlds just waiting to be discovered is staggering, if estimates prove to be accurate. In our Milky Way alone there could be hundreds of billions of planets, and so far we've found just a few thousand. The ultimate goal for planet hunting is to find an Earth-analogous planet that could help ascertain whether life could potentially grab a foothold outside of our Solar System.

The key to discovering an Earth-like planet is to find those that are within the habitable or 'Goldilocks' zone of a star, the area within which the conditions are thought to be 'just right' for water to form. Kepler-22b was the first such planet to be found and, while it is now thought to have a thick atmosphere that may be inhospitable to life, it was very influential in helping to spur the discovery of new Earth-like planets. One example of these was Gliese 581 g, a planet no more than

"Projects like the James Webb Telescope will bring Earth-sized exoplanets into view"

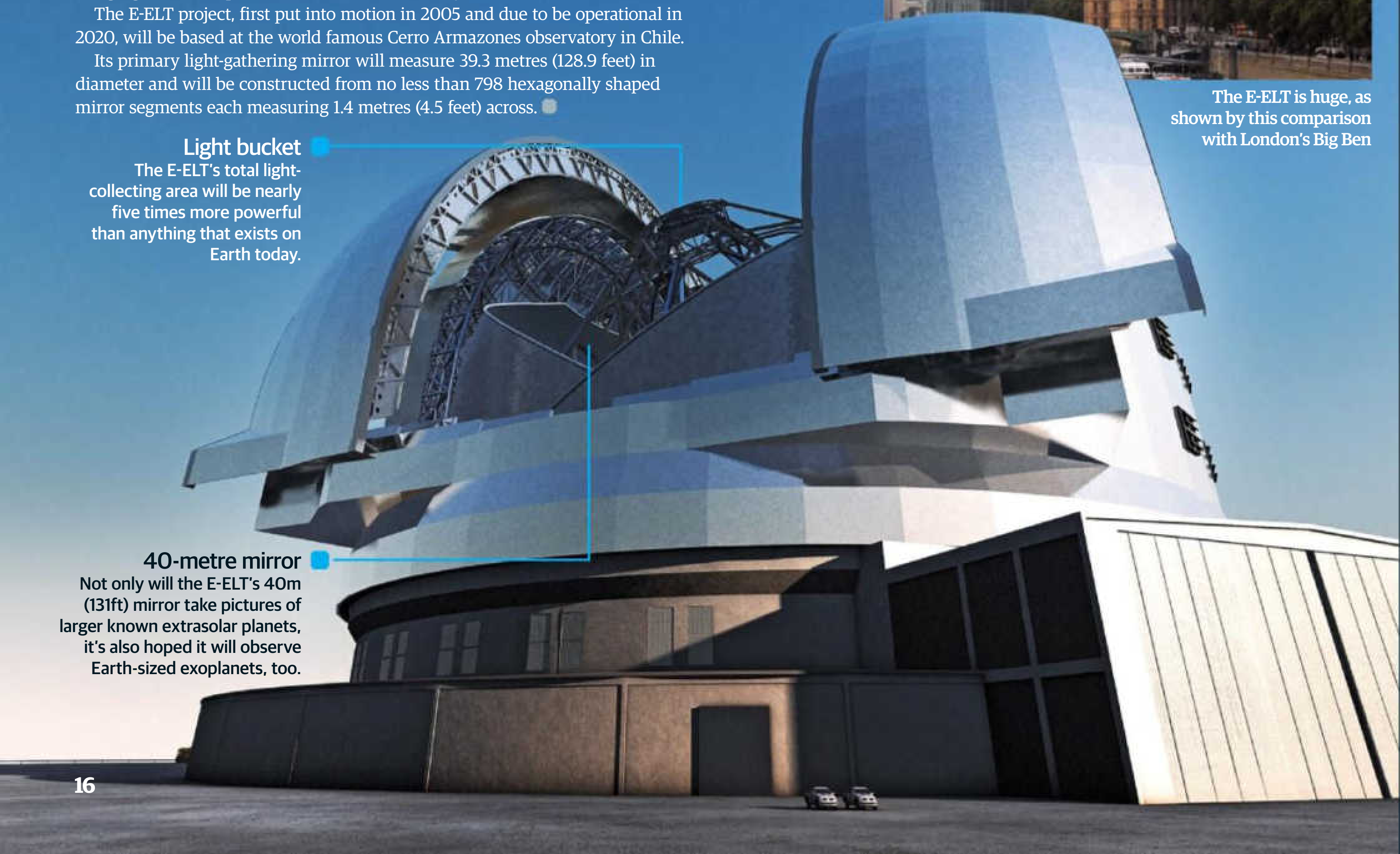
The search for extraterrestials

Often described as the world's biggest eye on the sky, the European Extremely Large Telescope (E-ELT) is one of a new breed of scopes that will be capable of bringing extrasolar planets, the universe's first objects and black holes into focus.

The E-ELT project, first put into motion in 2005 and due to be operational in 2020, will be based at the world famous Cerro Armazones observatory in Chile.

Its primary light-gathering mirror will measure 39.3 metres (128.9 feet) in diameter and will be constructed from no less than 798 hexagonally shaped mirror segments each measuring 1.4 metres (4.5 feet) across.

The E-ELT is huge, as shown by this comparison with London's Big Ben



four times the mass of Earth sitting right in the middle of the habitable zone of its host red dwarf star. While a year on this planet is only 37 days, observations suggest that Gliese 581 g may be a suitable planet on which life could reside.

Another potentially life-harbouring planet is HD 85512 b, a so-called 'Super-Earth', like Gliese 581 g, with a mass at least 3.6 times that of our home planet but with a temperature that could potentially allow for the existence of liquid water, which is thought to be one of the key components for life to form or survive. Over the next few years, as our methods of finding and characterising exoplanets become more and more sophisticated, it's likely that more Earth-like planets like these will be discovered all over the Milky Way.

3 amazing Earth-like planets

m = mass of the Earth
r = radius of the Earth

Gliese 581 g

Distance from Earth: 20 light years
Star: Gliese 581 **Constellation:** Libra
Discovered: 2010
Mass: 3.7m **Radius:** 1.3r
Temperature: -20°C

HD 85512 b

Distance from Earth: 36 light years
Star: HD 85512 **Constellation:** Vela
Discovered: 2011
Mass: 3.6m **Radius:** Unknown
Temperature: 25°C

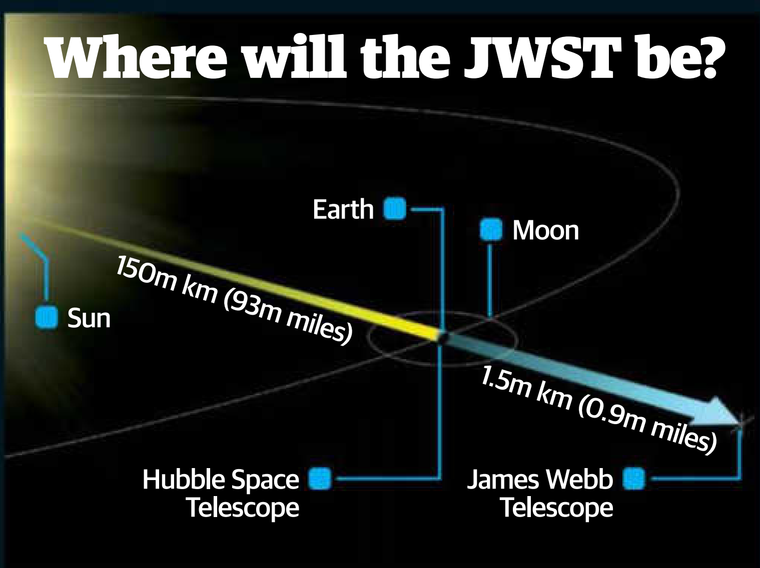
Kepler-22b

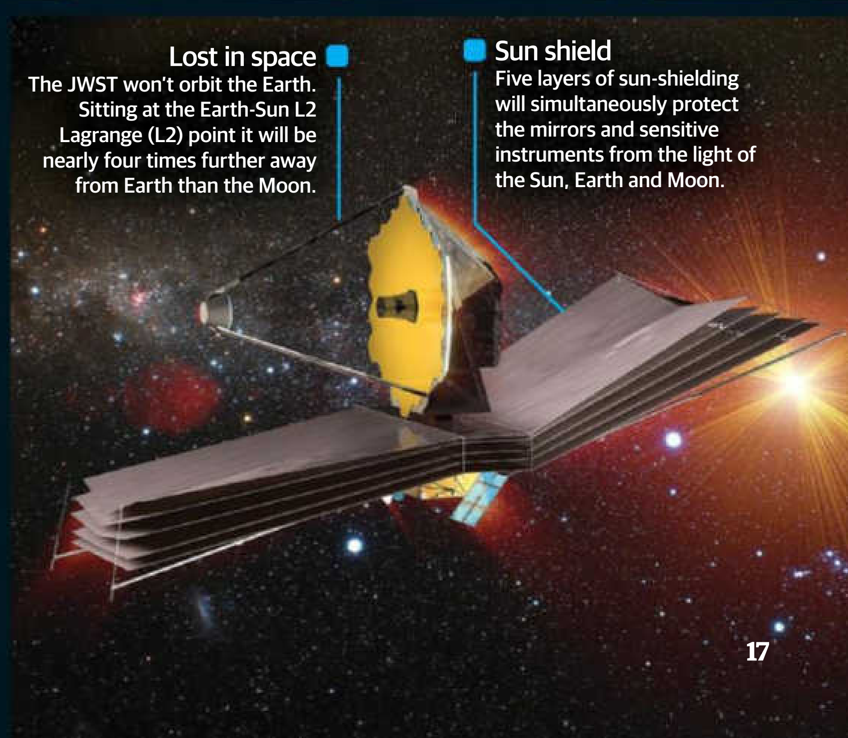
Distance from Earth: 620 light years
Star: Kepler-22 **Constellation:** Cygnus
Discovered: 2009
Mass: Unknown **Radius:** 2.4r
Temperature: -11.15°C

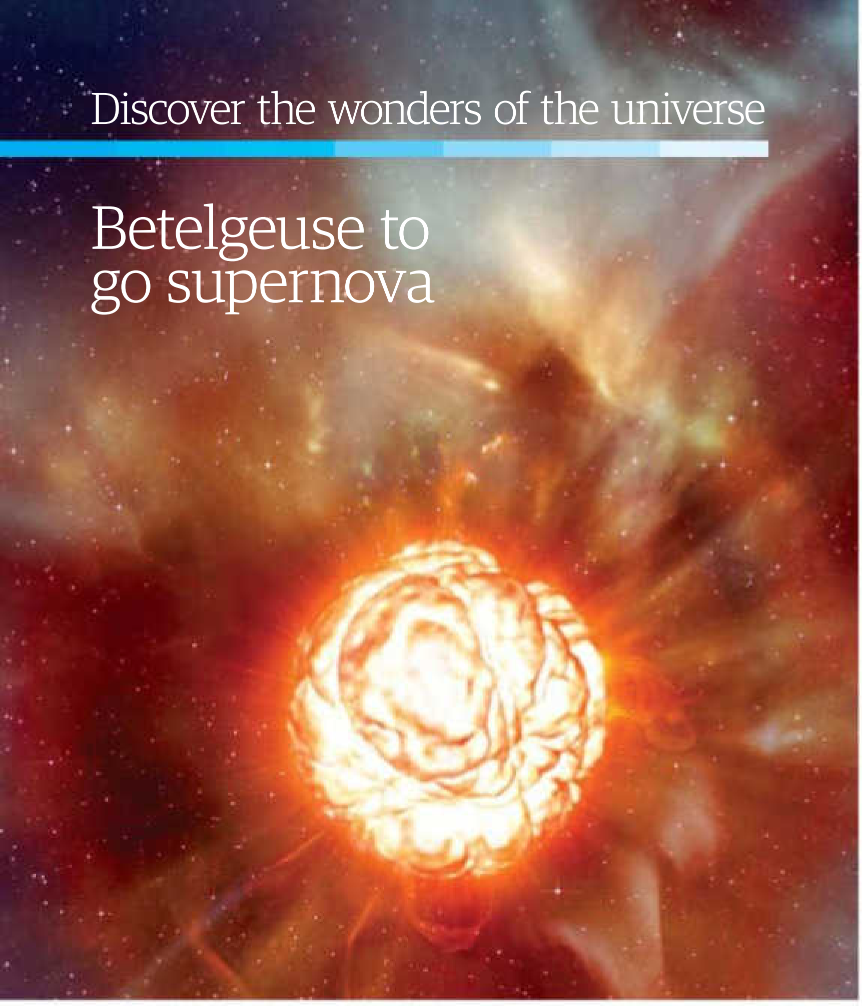
Most spectacular telescope ever

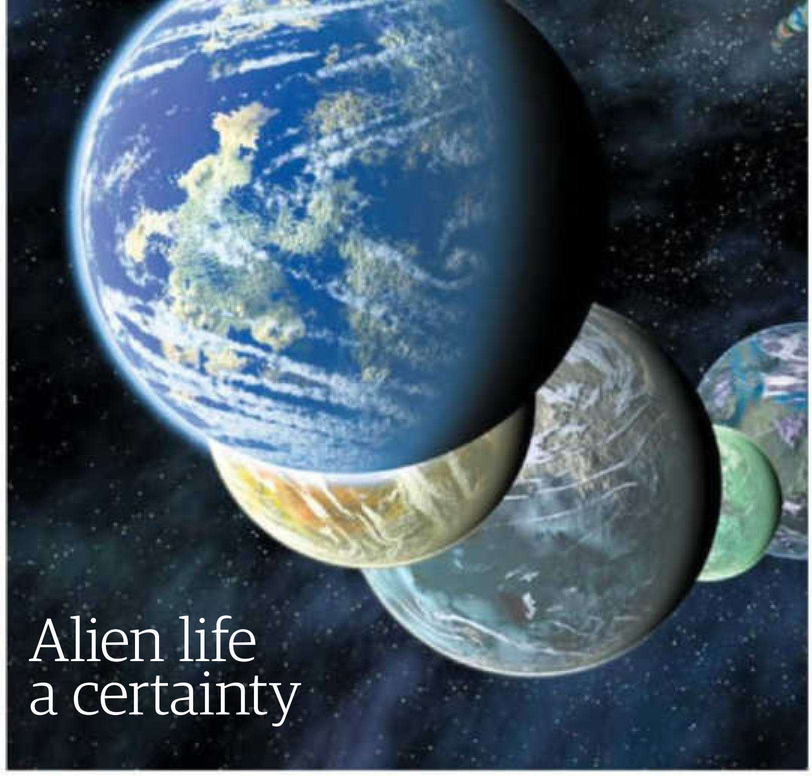
Named after the NASA administrator who created the Apollo space programme, the James Webb Space Telescope (JWST) is set to blast off to Earth orbit in 2018. Although often described as the successor to Hubble, the JWST will be a very different beast. First, it's much bigger. While Hubble was 13 metres (42 feet), JWST's sun shield alone is nearly twice the length at 22 metres (72 feet). The diameter of the primary mirror puts Hubble's 2.5-metre (8.2-foot) offering in the shade, too – at 6.5 metres (21.3 feet) it has a total light-collecting area of nearly 15 square metres (161.4 square feet).

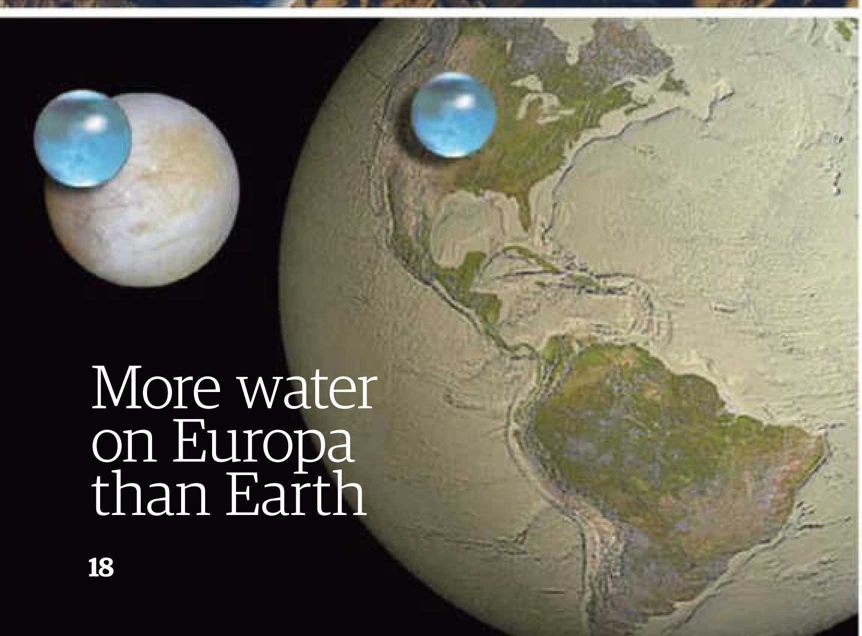
JWST is also designed to do its work in the infrared end of the spectrum, as opposed to Hubble's optical (and ultraviolet) wavelengths. This will let us see through the dust that clogs our view to the centre of our galaxy to offer us a glimpse of the supermassive black hole that resides there and investigate accretion discs of young stars so we can see how solar systems – and planets – form.











10 fascinating space facts you need to know

Meteorite-sized nuggets of fantastic space info that will blow your mind

Betelgeuse could go supernova
The red super giant star Betelgeuse is due to die at any moment. The event could see the star reach a comparable brightness to that of a full moon.

The Space Shuttle is no more
NASA's youngest Space Shuttle, Endeavour, having flown its last mission in May 2011 is now on display at the California Science Center in LA.

There's more water on Europa than Earth
Data acquired by NASA's Galileo spacecraft suggests there is up to three times more water under the surface of Saturn's moon Europa than on Earth.

The chance of extraterrestrial life is 100 per cent
That's according to the Drake equation, a mathematical equation used to estimate the number of extraterrestrial civilisations in our Milky Way galaxy. Mr Drake's own estimate came to over 10,000 alien civilisations.

Virgin Galactic set to take tourists into space
From late 2012 Spaceport America began hosting the first-ever space tourism flights courtesy of Virgin Galactic. It has 400 accepted reservations already on the books.

A soup can's worth of a neutron star would weigh more than the Moon itself
A neutron star is formed when a star of between eight and ten solar masses dies. A teaspoon of it would weigh more than everyone on Earth, while a soup can would weigh more than the Moon.

World's biggest telescope array set for completion
In 2012 the Atacama Large Millimeter/sub-millimeter Array (ALMA) in Chile was completed and consist of 66 twelve-metre and seven-metre diameter radio telescopes. It will be the biggest until the completion of the Square Kilometre Array in 2019.

The Moon is moving away
The Moon has been moving 38 millimetres away from the Earth every year since its formation.

Humans are going to Mars
NASA and Lockheed Martin hope to send humans to Mars by 2035 with the jointly created Orion spacecraft.

The Sun loses a billion kilograms every second
The sun burns through a billion kilograms of its own mass each second. That works out at about three Empire State Buildings every second!

Space tourism is go

Moon moving away from Earth

A tin heavier than the Moon

Mankind heading to Mars

Huge telescope array finished in 2012

The Sun is losing weight

Explore the galaxies

Discover where mankind has been and where it will go

30
The 1969 Lunar Lander

"Billionaires can book their flight around the Moon for as early as 2018"

51
5 amazing facts about rockets

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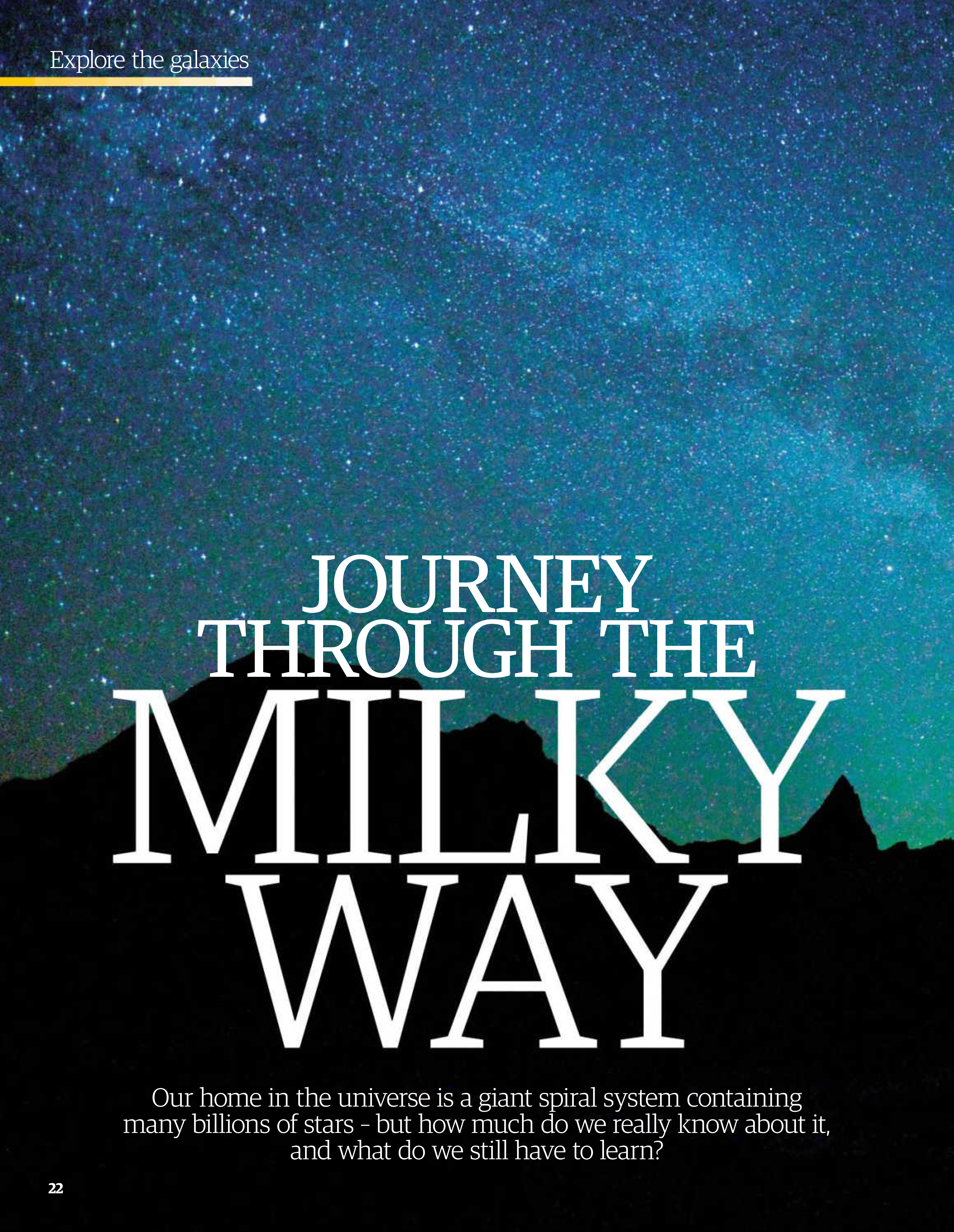


JOURNEY THROUGH THE MILKY WAY

Our home in the universe is a giant spiral system containing many billions of stars – but how much do we really know about it, and what do we still have to learn?

Look up at the sky on a dark, clear night and you can't miss the Milky Way – a broad swathe of pale light winding its way around the sky among many of the brightest individual stars. Ancient astronomers saw it as a stream of milk spilt across the sky by the goddess Hera when she suckled the hero Hercules, but today we know the Milky Way is something very different – an enormous disc of stars some 100,000 light years across, containing (at the latest estimate) around 200 billion individual stars.

Unsurprisingly, then, our Solar System is an insignificant speck within the overall scale of the Milky Way – all the planets and other large bodies orbiting the Sun are confined to a region just a few light *hours* across. In our part of the galaxy, stars are spaced far enough apart that even our nearest stellar neighbours appear as mere specks of light. The closest of all, the triple star Alpha Centauri, is still around 4.3 light years away.

The overall shape of our galaxy has been likened to two fried eggs placed back to back, with a broad, flat disc of scattered stars, gas and dust surrounding a bulging central hub where stars are more densely packed together. Our Solar System and its neighbours lie in a relatively sedate, outlying region of the Milky Way, about halfway between the centre and the edge. With a little understanding of the Milky Way's structure, the band of light across the night sky is easy to understand: when we look across the plane of the Milky Way's disc, we see far more stars lying in any given direction and these effectively merge together into a generalised glow. On the other hand, when we look 'up' or 'down', out of the galactic plane, we are staring into largely empty intergalactic space, with only relatively nearby stars in our part of the disc to get in the way.

In 1785, astronomer William Herschel made the first attempt to map the Milky Way in detail, by exhaustively counting the number of stars he could see in different directions across the sky. He proved beyond doubt that the Milky Way was a flattened plane, but unfortunately misunderstood its shape because he believed that our own Solar System was near the centre of the galaxy.

In the late-Twenties, Jan Oort set out to study the movement of individual stars in different parts of the sky. He soon confirmed that the Milky Way is rotating, showed that its centre lies in the direction of the constellation Sagittarius, and also proved that galaxies do not rotate like solid bodies – instead the stars closer to the galactic hub move more quickly along their orbits, while stars further out circle more slowly – a phenomenon known as 'differential rotation'. The Sun, for instance, takes around 200 million years to complete a single orbit. Later measurements in different parts of the disc showed that orbital speeds do not change as dramatically as

they should do if they are governed by the mass of the Milky Way's visible matter alone – evidence that our galaxy contains large amounts of transparent but weighty 'dark matter'.

Even today, our understanding of our galaxy is constantly evolving thanks to new theories and new observing technologies. Radio, infrared, ultraviolet and X-ray observations can pierce the dense clouds of stars and dust that obscure large parts of the Milky Way in visible light, while new analytical techniques allow astronomers to learn far more from the stars we can observe. So what is our current understanding of this enormous stellar system?

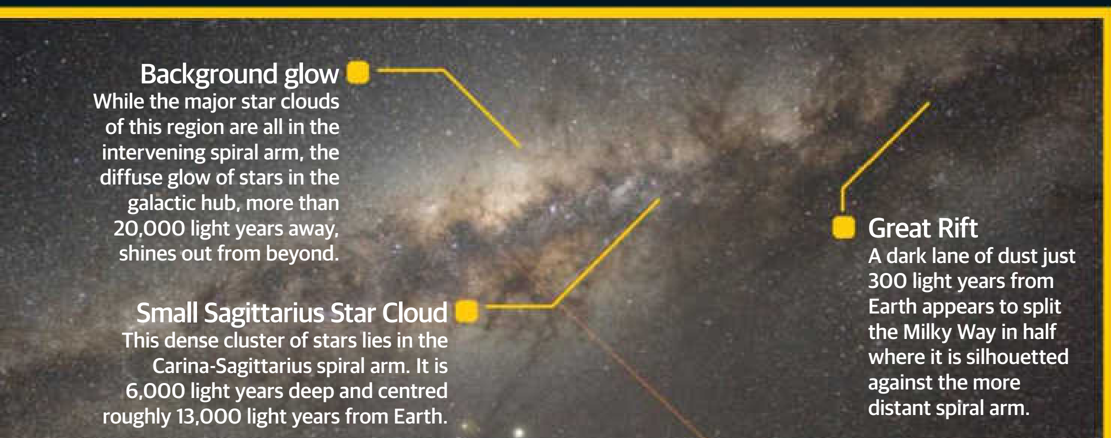
The Milky Way is a barred spiral galaxy, around 100,000 light years across and with a disc roughly 1,000 light years thick in most places. Its central hub is formed by a densely packed ball of stars roughly 8,000 light years in diameter, out of which a bar of stars some 27,000 light years long emerges. The bar points more or less directly towards our Solar System, and as a result its existence was uncertain until it was finally confirmed by NASA's infrared Spitzer Space Telescope in 2005.

> "The most brilliant stars don't survive long enough for their orbits to carry them out of the spiral arms"

Two major spiral arms emerge from the ends of this bar. Until recently, our galaxy was thought to have four major arms, but further observations have led to two of them being 'downgraded'. The two survivors are known as the Scutum-Centaurus Arm and the Perseus Arm. They alternate with the two recently demoted arms – the Sagittarius and Norma arms. The picture is complicated by numerous other disconnected regions that follow the general sweep of the spiral arms. For instance, our own Solar System lies on the inside edge of a 10,000 light year fork in the Sagittarius Arm, known as 'Orion Spur', while both the Sagittarius and Norma arms are thought to trail off into disconnected clumps that wrap their way around the galaxy's outer perimeter. The outer extension of the Norma Arm, which lies on our side of the galactic centre and is therefore more easily seen, is known as the Outer Arm.

The Milky Way's spiral arms are not permanent, linked structures – otherwise the differential rotation discovered by Jan Oort would cause them to 'wind up' after just a few rotations. Instead, they perpetually renew themselves. In fact, the arms seem to be celestial traffic jams, created where stars and gas in circular orbits around the galactic hub enter a spiral 'density wave' region where they are slowed down and jammed together. This triggers the creation of new star-forming nebulas that light up the spiral arms with the pinkish glow of hydrogen emission, and ultimately give birth to 'open clusters' of stars.

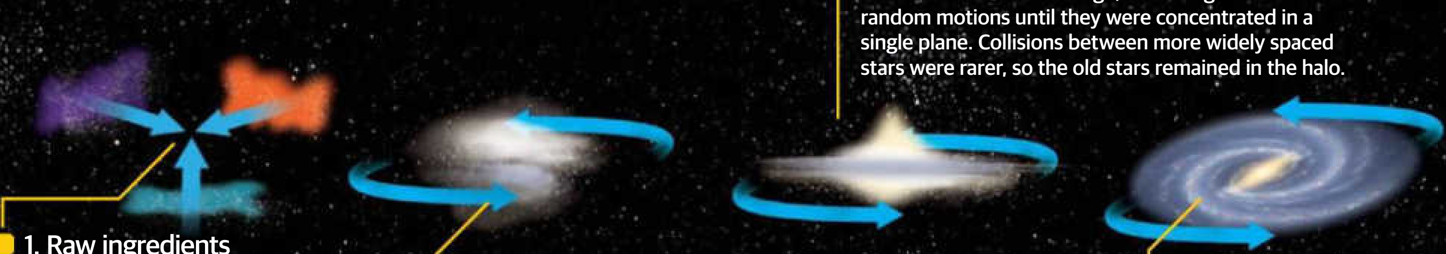
However, these stellar foundries are short-lived on a galactic timescale – they exhaust their supplies of star-forming gas within a few million years, and the heaviest stars squander their fuel in a few million more. As a result, the most brilliant stars don't survive long enough for their orbits to carry them out of the spiral arms – instead it's the more sedate, longer-lived stars like our own Sun that make it out of the traffic jam to continue their orbits around the galactic disc over billions of years.



Viewing our galaxy from Earth

As early as the 18th Century, astronomers realised that the winding path of the Milky Way across the sky is a result of our location in a broad, relatively flat plane of stars. But our Solar System's location sandwiched between the major spiral arms complicates the picture considerably, so that different arms in different parts of the sky run together and overlap in places to form a seamless river of light. The picture is further complicated by the presence of dark dust lanes that obscure the light of more distant star clouds: perhaps the most famous of these is the Great Rift, which runs through the constellations of Cygnus and Aquila. The brightest and broadest part of the Milky Way, meanwhile, lies in the direction of Sagittarius and Scorpius. It consists largely of the Carina-Sagittarius Arm and marks the direction of the hub and galactic centre. On the opposite side of the sky, meanwhile, the Perseus Arm runs around the outer edge of the galaxy as seen from our point of view.

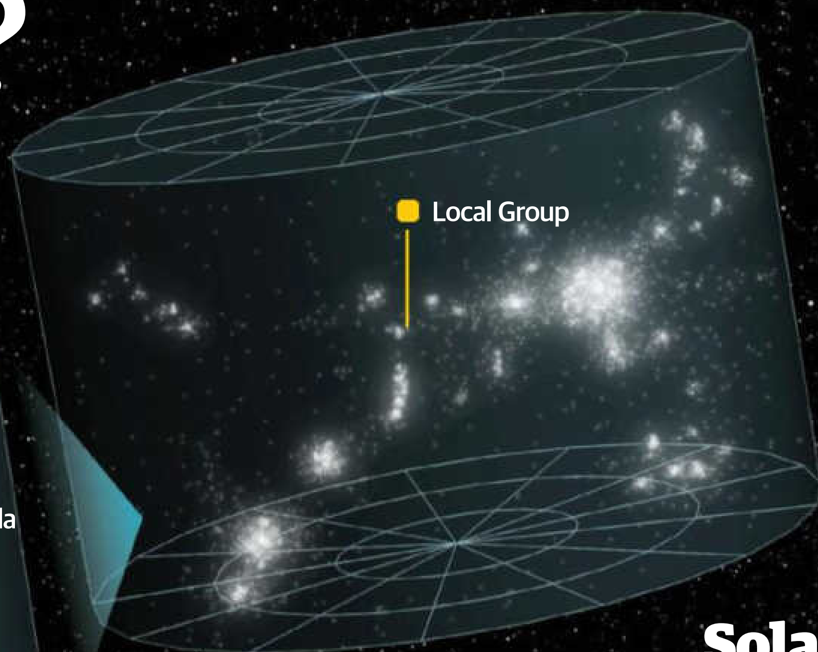
Birth of the Milky Way



Where is our galaxy?

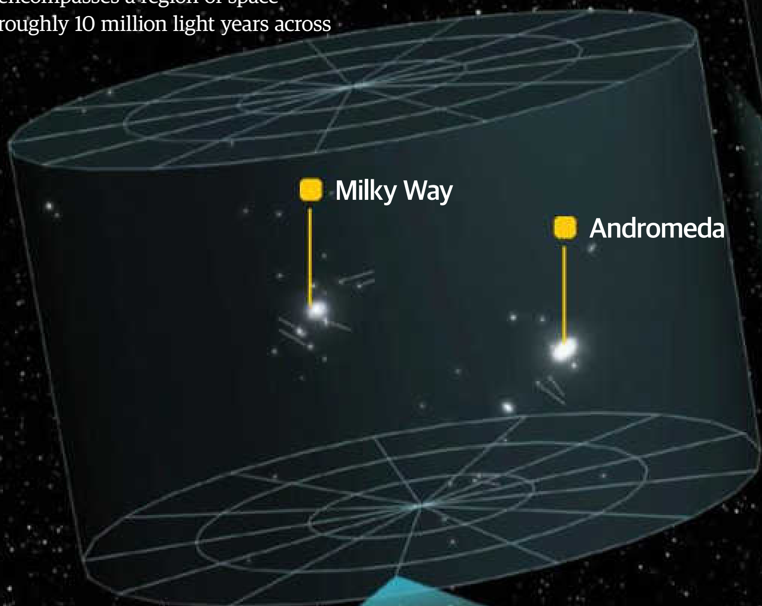
Virgo Supercluster

The Local Group lies on the outskirts of a galaxy supercluster centred around the Virgo Cluster, some 60 million light years away



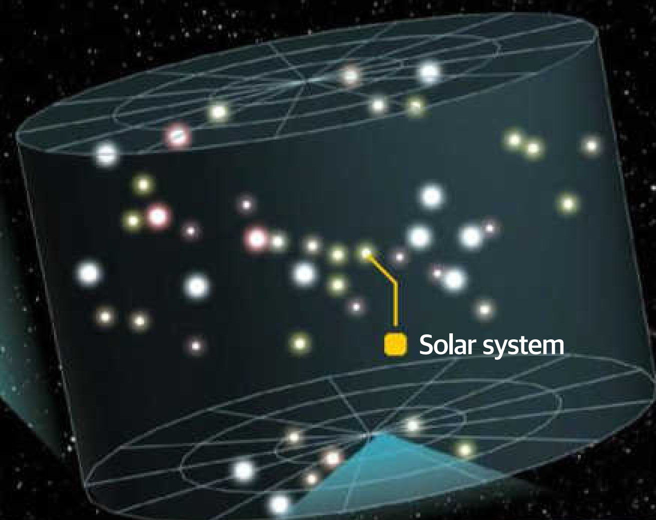
Local Group

This cluster of galaxies, dominated by the Milky Way and Andromeda, encompasses a region of space roughly 10 million light years across



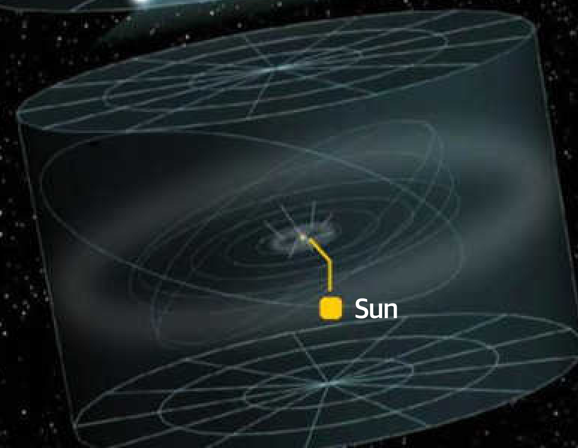
Solar neighbourhood

Our region of the Milky Way contains a mixture of single and multiple stars of many different types, separated by a few light years on average



Galactic influence

The Milky Way is roughly 100,000 light years across, but its gravitational influence covers a region several hundred thousand light years wide



Our Solar System

Out to the edge of the Kuiper belt (the zone of small, distant icy dwarf worlds) our Solar System is roughly a light day across

At the inner limit of the spiral arms, the bar and hub are surrounded by a structure known as the 5-kiloparsec Ring (one kiloparsec is around 3,260 light years). Although we cannot see it in visible light, the ring seems to contain huge concentrations of star-forming nebulas and young stars: it's probably the main generator of new stars in the Milky Way.

Above and below the main disc lies a relatively empty region known as the halo. Many faint, long-lived stars pass through this region on tilted orbits, but the halo's most obvious occupants are globular clusters – dense balls containing many tens of thousands of old, red and yellow stars that are generally found above and below the galactic hub. Similar red and yellow stars dominate the hub and bar – they are relatively poor in heavy elements, which allows them to shine for billions of years without evolving significantly. As a result, they are known as 'Population II' stars, in contrast to the younger, faster-evolving and heavy-element-enriched 'Population I' stars in the galactic disc.

Among all these stars, the huge majority are low-mass red and orange dwarfs – stars with a fraction of the mass of the Sun, which shine so faintly that they can only be seen when they are relatively nearby. Brighter and more massive stars are much rarer, but tend to shine out over huge distances and so appear more prominently in our skies. Similarly, ageing but brilliant red and orange giants are common among the naked-eye stars seen from Earth, but in fact far rarer than they might appear at first glance.

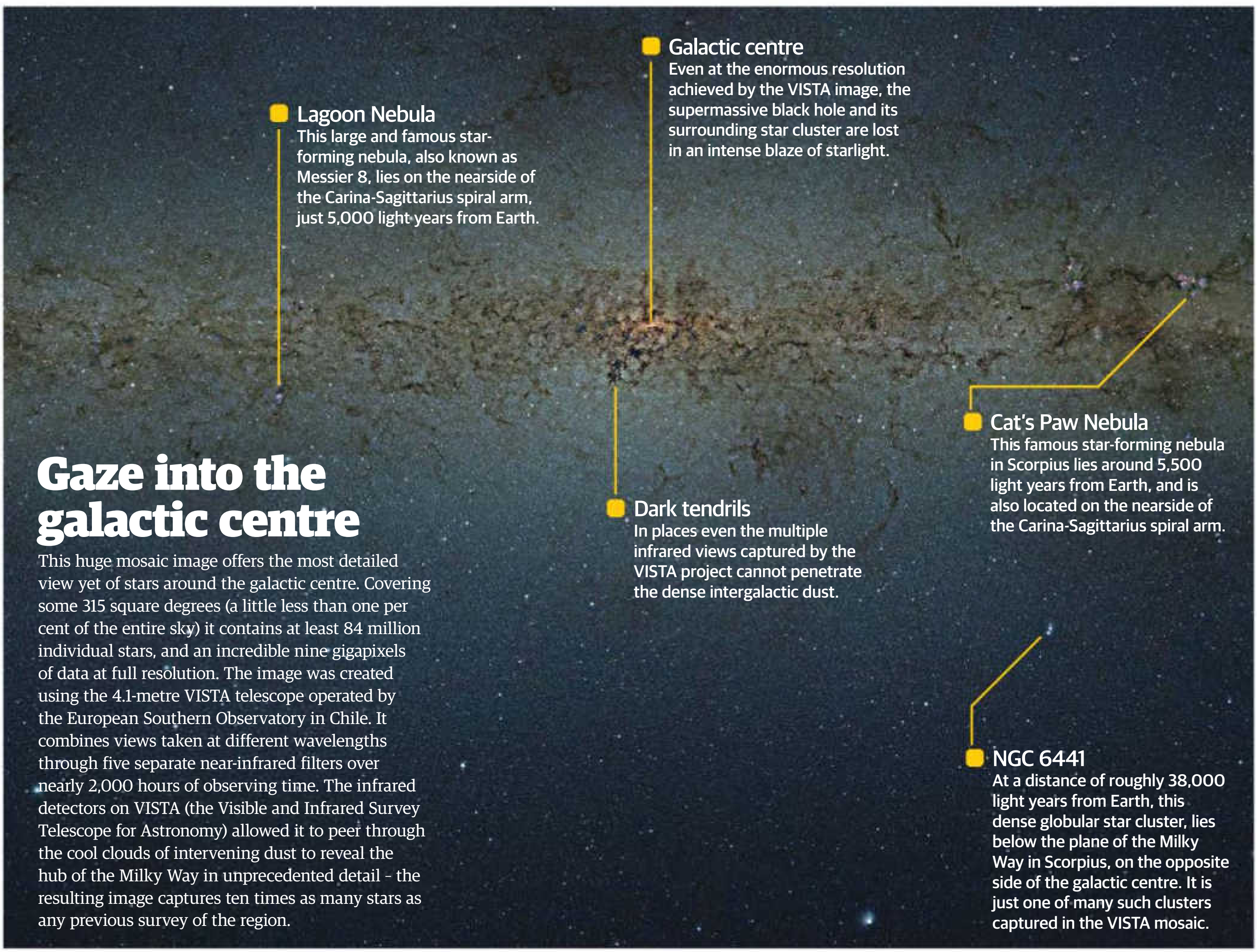
What's more, stars in our galaxy seem to be gregarious – although they gradually drift apart from the open clusters in which they form, many stars remain together in binary or multiple star systems. Recent research also suggests that planetary systems are also common – there may be at least as many planets as there are stars in the sky.

Within the hub, stars become more densely packed towards the centre of the Milky Way – the galactic core. Only X-rays, radio waves and some infrared waves can pass through these dense star clouds unaffected, but they reveal an intriguing picture of the strange and violent conditions in the core itself.

At radio wavelengths, the core is marked by a complex radio source known as Sagittarius A – it consists of a bubble-like structure (Sagittarius A West) a few tens of light years across – probably the remnant of an enormous supernova explosion. Embedded within this is a three-armed spiral called Sagittarius A East, roughly ten light years across. The middle of the spiral coincides with the densest concentration of stars in the Milky Way, and a third, point-like source of radio waves known as Sagittarius A* that is believed to mark the Milky Way's centre.

X-ray emissions reveal huge bubbles and twisted lobes of superhot gas across the region – a mix of supernova remnants and the effects of hot stellar

"The Milky Way is a major component of the Local Group – a small galaxy cluster some 10 million light years across"



Galactic centre
Even at the enormous resolution achieved by the VISTA image, the supermassive black hole and its surrounding star cluster are lost in an intense blaze of starlight.

Lagoon Nebula
This large and famous star-forming nebula, also known as Messier 8, lies on the nearside of the Carina-Sagittarius spiral arm, just 5,000 light years from Earth.

Cat's Paw Nebula
This famous star-forming nebula in Scorpius lies around 5,500 light years from Earth, and is also located on the nearside of the Carina-Sagittarius spiral arm.

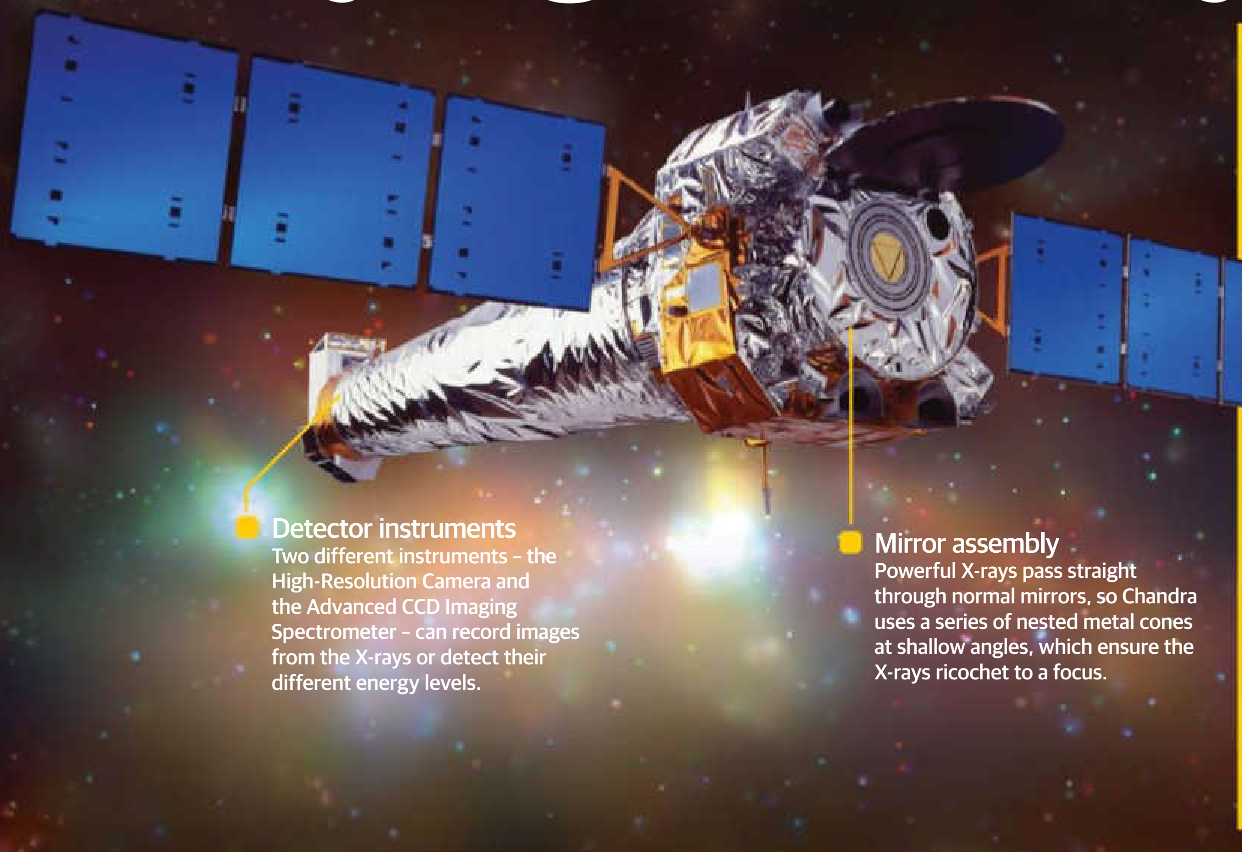
Dark tendrils
In places even the multiple infrared views captured by the VISTA project cannot penetrate the dense intergalactic dust.

NGC 6441
At a distance of roughly 38,000 light years from Earth, this dense globular star cluster, lies below the plane of the Milky Way in Scorpius, on the opposite side of the galactic centre. It is just one of many such clusters captured in the VISTA mosaic.

Gaze into the galactic centre

This huge mosaic image offers the most detailed view yet of stars around the galactic centre. Covering some 315 square degrees (a little less than one per cent of the entire sky) it contains at least 84 million individual stars, and an incredible nine gigapixels of data at full resolution. The image was created using the 4.1-metre VISTA telescope operated by the European Southern Observatory in Chile. It combines views taken at different wavelengths through five separate near-infrared filters over nearly 2,000 hours of observing time. The infrared detectors on VISTA (the Visible and Infrared Survey Telescope for Astronomy) allowed it to peer through the cool clouds of intervening dust to reveal the hub of the Milky Way in unprecedented detail – the resulting image captures ten times as many stars as any previous survey of the region.

Studying the Milky Way



Mission profile

Chandra X-ray Observatory

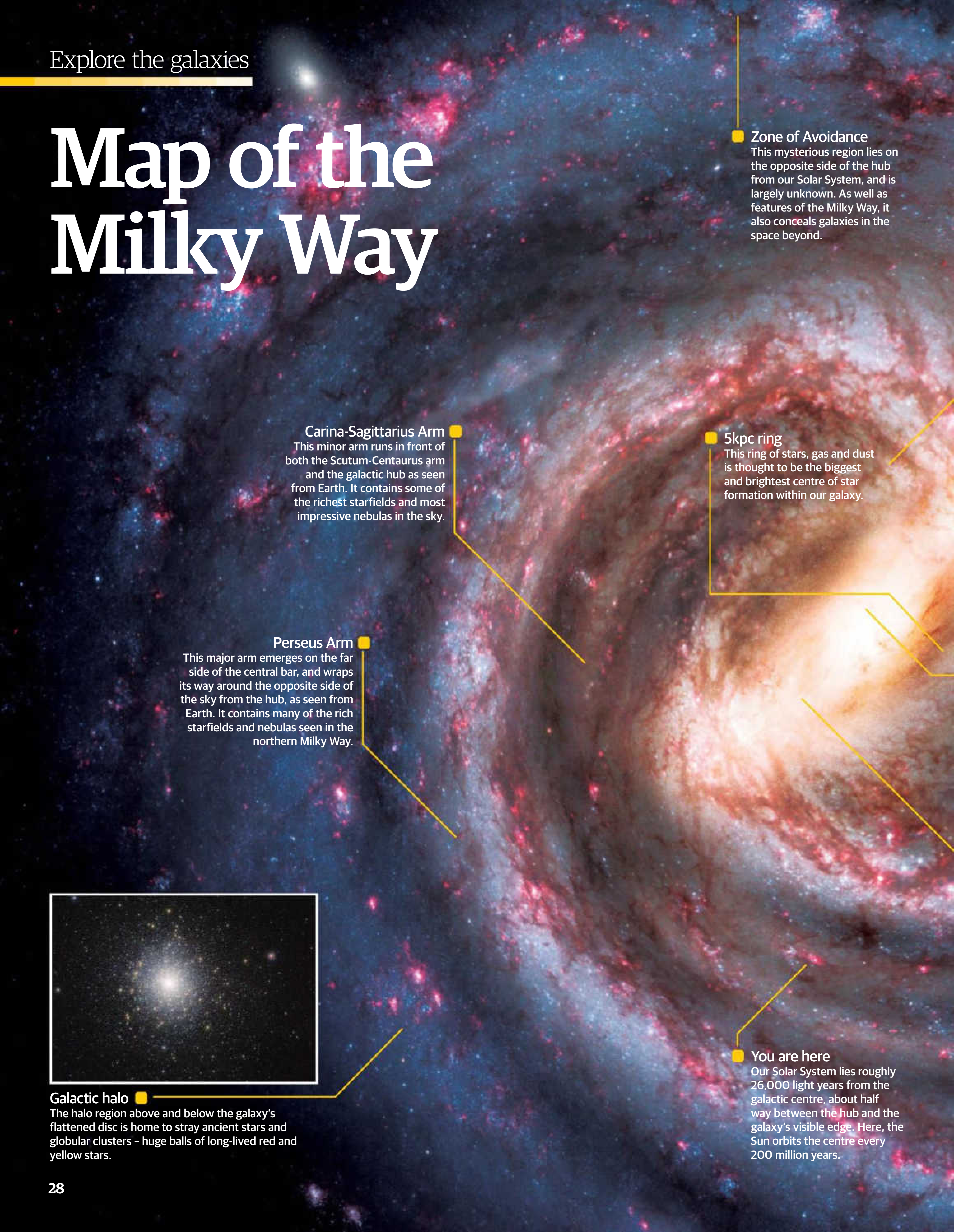
Launch date: 23 July 1999
Launch vehicle: Space Shuttle Columbia
Mass: 4,790kg
Telescope diameter: 1.2m
Mission: Chandra was designed to image the high-energy X-ray sky at higher resolutions than ever before, detecting phenomena such as hot interstellar and intergalactic gas clouds, black holes and other stellar remnants.
Key discoveries: Chandra has allowed the region around Sagittarius A* to be imaged in detail, while the X-ray echoes it has detected have shown that the supermassive black hole has been active in the recent past.

Mission profile

Spitzer Infrared Space Observatory

Launch date: 25 August 2003
Launch vehicle: Delta II
Mass: 950kg
Telescope diameter: 0.85m
Mission: Spitzer was designed to study a wide range of objects, from star-forming nebulas and newborn solar systems to distant galaxies. Although the coolant required for its primary mission was exhausted in May 2009, it is still operational in its 'Warm Mission' phase.
Key discoveries: Spitzer's infrared vision allowed it to pierce the dust that blocks our view of the galactic centre, providing the first detailed images of the giant star clusters and tortured gas clouds found in the region.

Map of the Milky Way



Zone of Avoidance
This mysterious region lies on the opposite side of the hub from our Solar System, and is largely unknown. As well as features of the Milky Way, it also conceals galaxies in the space beyond.

Carina-Sagittarius Arm
This minor arm runs in front of both the Scutum-Centaurus arm and the galactic hub as seen from Earth. It contains some of the richest starfields and most impressive nebulas in the sky.

5kpc ring
This ring of stars, gas and dust is thought to be the biggest and brightest centre of star formation within our galaxy.

Perseus Arm
This major arm emerges on the far side of the central bar, and wraps its way around the opposite side of the sky from the hub, as seen from Earth. It contains many of the rich starfields and nebulas seen in the northern Milky Way.

Galactic halo
The halo region above and below the galaxy's flattened disc is home to stray ancient stars and globular clusters – huge balls of long-lived red and yellow stars.

You are here
Our Solar System lies roughly 26,000 light years from the galactic centre, about half way between the hub and the galaxy's visible edge. Here, the Sun orbits the centre every 200 million years.

Scutum-Centaurus Arm
This major spiral arm emerges from the near end of the galaxy's central bar, but lies largely on the opposite side of the hub from Earth.

SagDEG
Discovered in 1994 as an unusual concentration of stars on the far side of the galactic hub, the Sagittarius Dwarf Elliptical is a small galaxy in the process of being torn to shreds by the Milky Way's gravity.

Sagittarius A*
The supermassive black hole at the centre of our galaxy weighs more than 4 million Suns, but only gives its presence away through X-ray and radio emission.

Galactic hub
The central bulge of the Milky Way is roughly 8,000 light years in diameter and dominated by tightly packed, long-lived red and yellow stars.

winds blowing out from massive stars. Infrared telescopes, meanwhile, show the distribution of stars themselves – the region is home to two of the largest open clusters in the galaxy, the Quintuplet Cluster and the Arches Cluster. A third cluster surrounds the Sagittarius A* region itself, but while its individual stars have been mapped, none coincides exactly with the mysterious radio source.

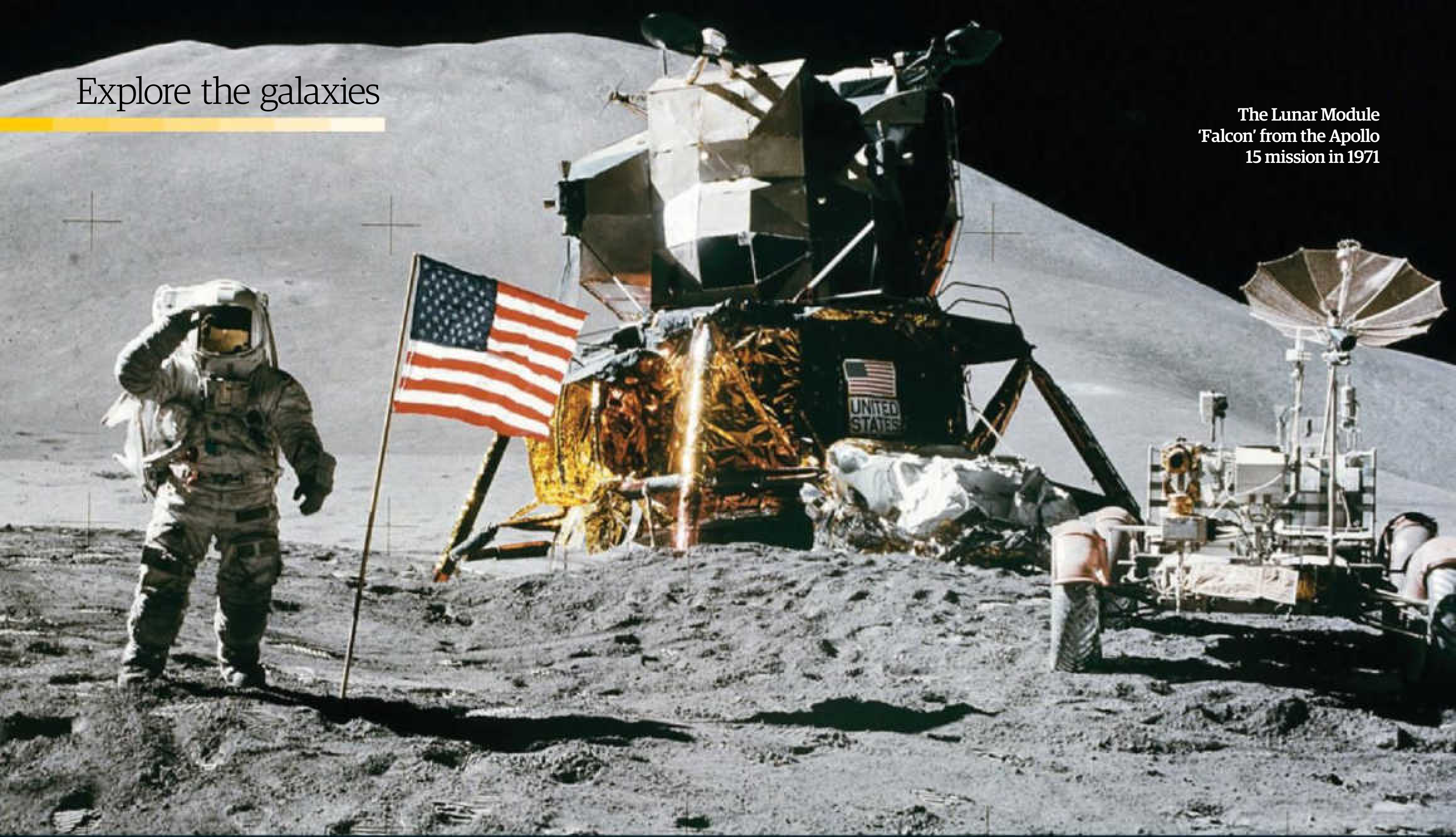
Since the Seventies, astronomers have suspected that Sagittarius A* might mark the location of an invisible black hole with the mass of millions of Suns, but the evidence to back this up has only recently been found. By mapping the central star cluster over several years, astronomers have plotted the orbits of two stars that orbit the object every few years. Based on the speed of these stars, Sagittarius A* must contain the mass of at least 4 million Suns concentrated in a region roughly the size of Uranus's orbit around the Sun. With such enormous density, it can only be a supermassive black hole.

However, Sagittarius A* seems surprisingly quiet compared to similar objects elsewhere in the universe – other supermassive black holes in distant galaxies wreak havoc with their surroundings. Astronomers think the big difference is that these black holes are feeding on material that strays too close. Sagittarius A*, on the other hand, seems to have long ago cleared out its immediate surroundings, and anything that still orbits in the central region stays safely out of reach.

Recent discoveries, however, suggest that Sagittarius A* may have been active surprisingly recently. In 2007, NASA's Chandra satellite discovered X-ray 'echoes', created as radiation when an event roughly 50 years previously affected gas clouds near the central black hole. It seems likely that Sagittarius A* took a substantial snack at this time, when a large gas cloud strayed too close. And in 2010, the Fermi Gamma-ray Space Telescope found evidence for an even larger outburst thousands of years ago.

There's one final question that's worth asking about our galaxy – where does it end? Although the spiral arms seem to lose their intensity and the number of disc stars falls off dramatically over 50,000 light years from the hub, a disc of neutral hydrogen gas extends out to almost 100,000 light years and seems to retain the overall spiral structure. The Milky Way's gravitational influence extends even further – the halo of stars and globular clusters reaches out to around 150,000 light years or more. However, beyond this distance the orbits of halo objects are disrupted by two interlopers – the Magellanic Clouds. Until recently, these two irregular clouds of gas were believed to be in orbit around our galaxy, but it now seems that they are merely passing by on their own paths through space.

On a larger scale, the Milky Way is one of the major components of the Local Group – a galaxy cluster 10 million light years across. The other is the Andromeda Galaxy, some 2.5 million light years away. These two galaxies exert a strong influence on everything in their vicinity, and are approaching each other at 110 kilometres per second. They will eventually collide and merge together about 4 billion years from now in a process that will signal the end of the Milky Way as an independent galaxy.



The Lunar Module 'Falcon' from the Apollo 15 mission in 1971

The 1969 Lunar lander

The Lunar Module was the first manned spacecraft specifically built to deliver men to the Moon

This two-stage spacecraft was built by the Grumman Aircraft Engineering Corporation to ferry two astronauts and scientific equipment to the surface of the Moon. The 6.7-metre (22-foot) tall craft had an aluminium frame with titanium fittings and was covered with layers of aluminised Kapton and aluminised Mylar to provide thermal protection against micrometeoroids.

The Apollo Command Module carried it into lunar orbit, and two of the three crew transferred to it and used the descent engine to land on the Moon. After deploying scientific experiments and collecting samples, the ascent stage blasted off using the descent stage as a launching pad. Back in lunar orbit, it docked with the Command Module, and once the astronauts were back on board the ascent stage was jettisoned. Before the Lunar Module (LM) could be used for the Moon landing mission it went through a rigorous programme of development and testing.

In 1962, the first designs envisaged a squat vehicle with large windows but by 1965 it evolved into a lighter and taller, triangular-windowed craft.

The Apollo 5 mission was the first test flight of the LM-1 on 22 January 1968. A Saturn 1B rocket put the unmanned craft into Earth orbit where the descent and ascent rocket engines were tested to simulate a mission abort and a deceleration burn required for a lunar landing.

The mission was deemed so successful that a further test mission with LM-2 was abandoned. Apollo 9 became the first manned mission for LM-3 ('Spider'), which was launched into Earth orbit on 3 March 1969. Commanded by James McDivitt, the systems of the LM were tested and it performed docking manoeuvres with the Command Module.

LM-4 'Snoopy' was the first LM to be tested in lunar orbit, and its closest approach took it within 15.6 kilometres (9.7 miles) of the Moon before it returned to the Command Module. This dress rehearsal in May 1969 went perfectly but the LM was a test version that was too heavy to launch itself off the lunar surface.

Finally, Apollo 11's LM-5 'Eagle' took Neil Armstrong and Buzz Aldrin to the Moon on 20 July 1969. However, it was not a straightforward landing as the astronauts had to override their craft's computer otherwise they would have landed in an unplanned rocky area. Apollo 12's LM-6 'Intrepid' in November 1969 also made a successful landing on the Moon. Despite the odd glitch, the Moon missions ran successfully until the Apollo 13 mission.

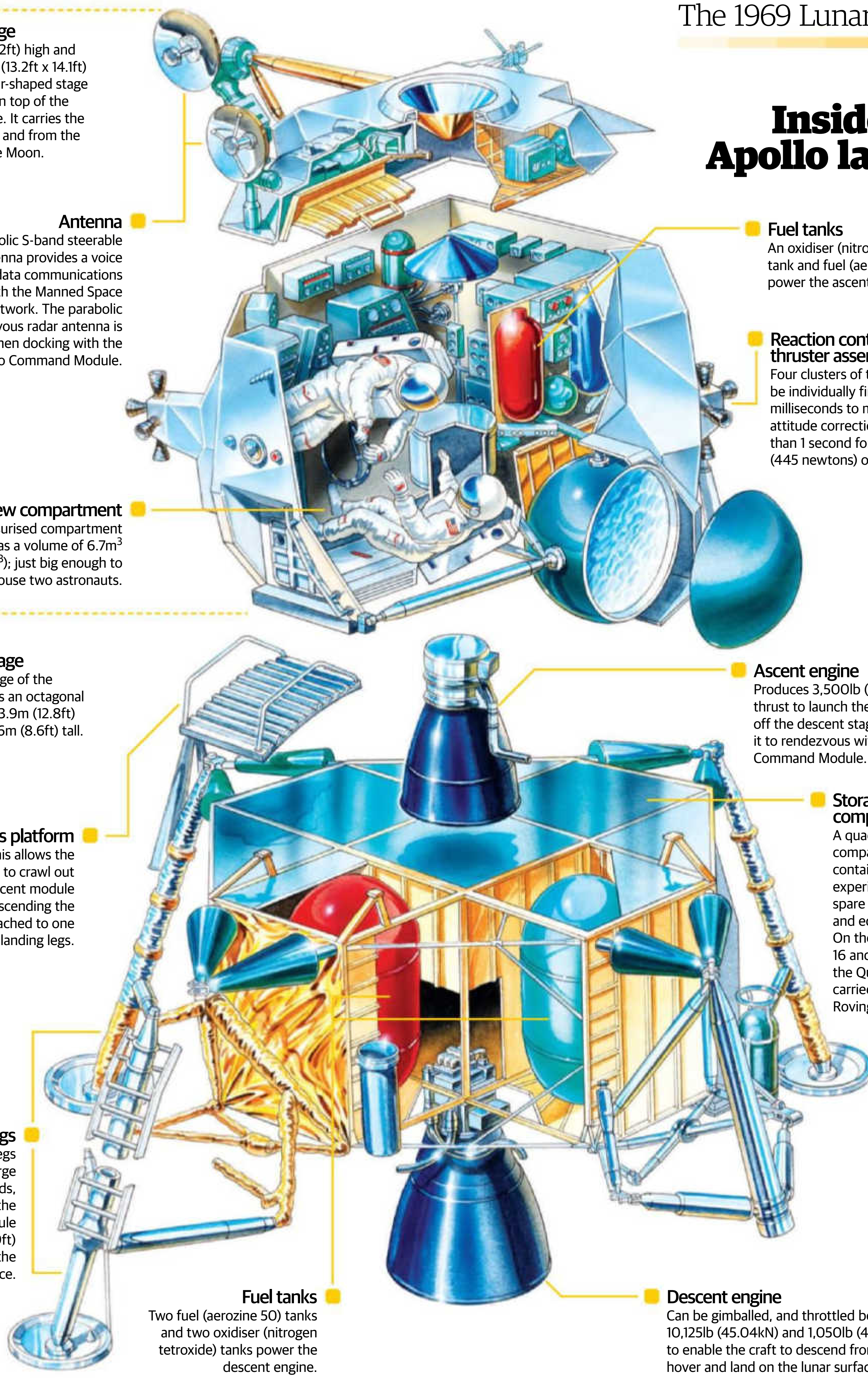
At a distance of around 320,000 kilometres (200,000 nautical miles) from Earth an oxygen tank in the Command Service Module exploded, and it immediately became a mission to safely return to Earth rather than a trip to the Moon. For four days the crew took refuge in the LM-7 'Aquarius' until they could use the Command Module to re-enter the Earth's atmosphere.

From Apollo 12 to Apollo 14, which used LM-8 'Antares' to land on the Moon in February 1971, H-series precision Landing Modules were used that could sustain two-day long stays on the Moon. LM-9 a H-series module was scheduled for the Apollo 15, but it was replaced with the improved J module series that carried the Lunar Roving Vehicle. J-series modules continued to be used up to the last Apollo 17 mission in December 1972.

In the late-Sixties, there were plans for an LM Truck that would replace the manned ascent stage of the LM with a cargo-carrying stage. This would be capable of delivering 5,000 kilograms (11,000 pounds) of equipment and supplies to support manned Lunar activities.

It is remarkable that after more than 40 years this is the only manned vehicle to land on the Moon.

Inside the Apollo lander



Ascent stage
This 2.8m (9.2ft) high and 4.0m x 4.3m (13.2ft x 14.1ft) wide, irregular-shaped stage is mounted on top of the descent stage. It carries the astronauts to and from the surface of the Moon.

Antenna
The parabolic S-band steerable antenna provides a voice and data communications link with the Manned Space Flight Network. The parabolic rendezvous radar antenna is used when docking with the Apollo Command Module.

Crew compartment
The pressurised compartment has a volume of 6.7m^3 (235ft^3); just big enough to house two astronauts.

Fuel tanks
An oxidiser (nitrogen tetroxide) tank and fuel (aerozine 50) tank power the ascent engine.

Reaction control thruster assembly
Four clusters of thrusters can be individually fired for a few milliseconds to make fine attitude corrections, or longer than 1 second for 100 pounds (445 newtons) of steady thrust.

Descent stage
The lower stage of the spacecraft has an octagonal prism shape, 3.9m (12.8ft) across and 2.6m (8.6ft) tall.

Egress platform
This allows the astronauts to crawl out of the ascent module before descending the ladder attached to one of the landing legs.

Landing legs
The four legs have large landing pads, and hold the Lunar Module 1.5m (4.9ft) above the lunar surface.

Ascent engine
Produces 3,500lb (16kN) of fixed thrust to launch the ascent stage off the descent stage, and enables it to rendezvous with the Apollo Command Module.

Storage compartments
A quadrant of compartments contain lunar surface experiments, spare batteries and equipment. On the Apollo 15, 16 and 17 missions, the Quadrant 1 bay carried the Lunar Roving Vehicle.

Fuel tanks
Two fuel (aerozine 50) tanks and two oxidiser (nitrogen tetroxide) tanks power the descent engine.

Descent engine
Can be gimballed, and throttled between 10,125lb (45.04kN) and 1,050lb (4.7kN) of thrust to enable the craft to descend from lunar orbit, hover and land on the lunar surface.

10 DARING SPACE RESCUES

From fearless spacewalks to death-defying descents to Earth, space is filled with stories of heroism that brought missions back from the brink of near-disaster


STBD FWD
STBD FWD

1 Apollo 13

Disaster date: 13 April 1970
What happened: A faulty oxygen tank turned the third manned mission to the Moon into an epic fight for survival

In April 1970, John Swigert, Fred Haise and James Lovell left Earth on a mission bound for the Moon. After 55 hours the crew took part in a live television broadcast back to Earth, but just nine minutes later, disaster struck.

Ground tests before the launch had revealed a problem with oxygen tank 2. It had been used previously on Apollo 10, but had been damaged and had undergone repairs. Before launch, it would not empty properly, so engineers used the internal heater to boil off the extra oxygen. Unknown to them, during the procedure, the on-off switch became welded shut.

The fault went unnoticed and during the flight the temperature inside the tank skyrocketed. When the crew stirred the tanks 56 hours into their mission, they didn't realise that the insulation on the electrical wires inside had melted. As the fans turned, the wires touched, shorting out and setting the insulation alight.

The astronauts heard a loud bang and felt the spacecraft rumble. Swigert contacted mission control and said the famous words, "Houston, we've had a problem here". The oxygen dials showed that one tank was empty and the level in the second was falling.

The crew had trained in simulations and remained calm, but tank one had also been damaged and their oxygen supply was rapidly running out. Before launch, the crew had practised using the Lunar Module as a lifeboat in case of emergencies. It carried enough oxygen and battery power for almost two days. With just a few minutes of power left the crew shut the Command Module down and transferred to the Lunar Module.

Mission control calculated that it would take two five-minute burns to loop Apollo 13 round the far side of the Moon and back towards Earth, but it would take several days to rescue them. The Lunar Module had only been designed to operate for two days. The temperature plummeted and the men had to drastically cut their water intake and they barely slept as they returned towards the Earth.

The Lunar Module was not heat shielded, so in order to re-enter Earth's atmosphere, the crew had to return to the Command Module. It'd never been switched off during a mission before but as they approached Earth, the astronauts managed to successfully power the module back on.

As the crew dropped through the atmosphere, communications cut out and mission control held its breath. Finally, they received confirmation that everyone was alright and the astronauts had splashed down safely in the Pacific Ocean.

Mission timeline

8. Return home
Time: 142:40:45
Apollo 13 re-entered the atmosphere almost four days after the disastrous explosion, carrying the exhausted crew to a gentle ocean splashdown.

7. Assessing the damage
Time: 138:01:48
The damaged service module was released into space, and the crew were able to view the extent of the explosion for the first time.

Earth

Powering on
Time: 140:10:00
The Command Module was brought back online shortly before the crew reached Earth.

"Mission control held its breath as the crew dropped through the atmosphere"

1. Lift-off
Time: 00:00:00
Apollo 13 was the third manned mission to the lunar surface, and the crew planned to explore the Fra Mauro region on the near-side of the Moon.

2. Television transmission
Time: 55:14:00
Shortly before the explosion, the crew took part in a live television broadcast back to Earth, showing viewers what life was like inside the module.

The Apollo 13 crew had to make use of the Lunar Module (on the left) in their fight for survival

6. Running repairs
Time: 93:30:00
After just a day and a half in the module, carbon dioxide levels rose dangerously high, and mission control had to invent a quick fix to replace the filters.

5. Emergency correction
Time: 61:29:43
The crew executed the first burn to swing Apollo 13 around the Moon and back towards the Earth.

4. To the lifeboat
Time: 57:43:00
As the remaining oxygen dwindled, the crew abandoned the Command Module and retreated to the safety of the Lunar Module, which had its own separate supplies.

Moon

3. "Houston, we've had a problem"
Time: 55:55:20
After the broadcast had ended, the crew were asked to stir the oxygen tanks. Tank two was faulty, and the procedure triggered a catastrophic explosion in the support module, venting their vital oxygen supply and taking the fuel cells offline.

NASA's Apollo 13 report

"The Apollo 13 accident, which aborted man's third mission to explore the surface of the Moon, is a harsh reminder of the immense difficulty of this undertaking.

The total Apollo system of ground complexes, launch vehicle, and spacecraft constitutes the most ambitious and demanding engineering development ever undertaken by man. For these missions to succeed, both men and equipment must perform to near perfection. That this system has already resulted in two successful lunar surface explorations is a tribute to those men and women who conceived, designed, built, and flew it.

Perfection is not only difficult to achieve, but difficult to maintain. The imperfection in Apollo 13 constituted a near disaster, averted only by the outstanding performance on the part of the crew and the ground control team which supported them.

The Apollo 13 Review Board was charged with the responsibilities of reviewing the circumstances surrounding the accident, of establishing the probable causes of the accident, of assessing the effectiveness of flight recovery actions, of reporting these findings, and of developing recommendations for corrective or other actions. The Board has made every effort to carry out its assignment in a thorough, objective, and impartial manner. In doing so, the Board made effective use of the failure analyses and corrective action studies carried out by the Manned Spacecraft Center and was very impressed with the dedication and objectivity of this effort.

The Board feels that the nature of the Apollo 13 equipment failure holds important lessons which, when applied to future missions, will contribute to the safety and effectiveness of manned space flight."

2 Rosetta/Philae

Disaster date: 12 November 2014
What happened: The ten-year mission to land a probe on a comet came close to failure when the harpoons designed to anchor the Philae lander did not deploy

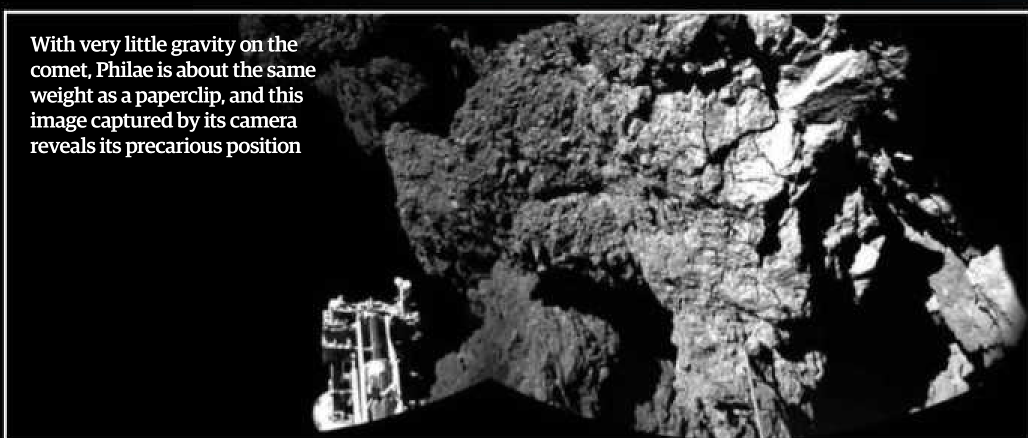
The Rosetta spacecraft had chased comet 67P/Churyumov-Gerasimenko for over ten years, travelling 6.4 billion kilometres (4 billion miles) before coming into orbit on 6 August 2014. The next phase of the mission was to soft-land the Philae probe on to the surface so that it could sample the comet with its on-board laboratory.

The team aimed to slow the probe to one metre (3.3 feet) per second as it neared the surface, allowing its three legs to land gently on a flat patch of ground. Harpoons would then be deployed to bolt the lander to the floor. However, when Philae touched down it did not quite go as planned.

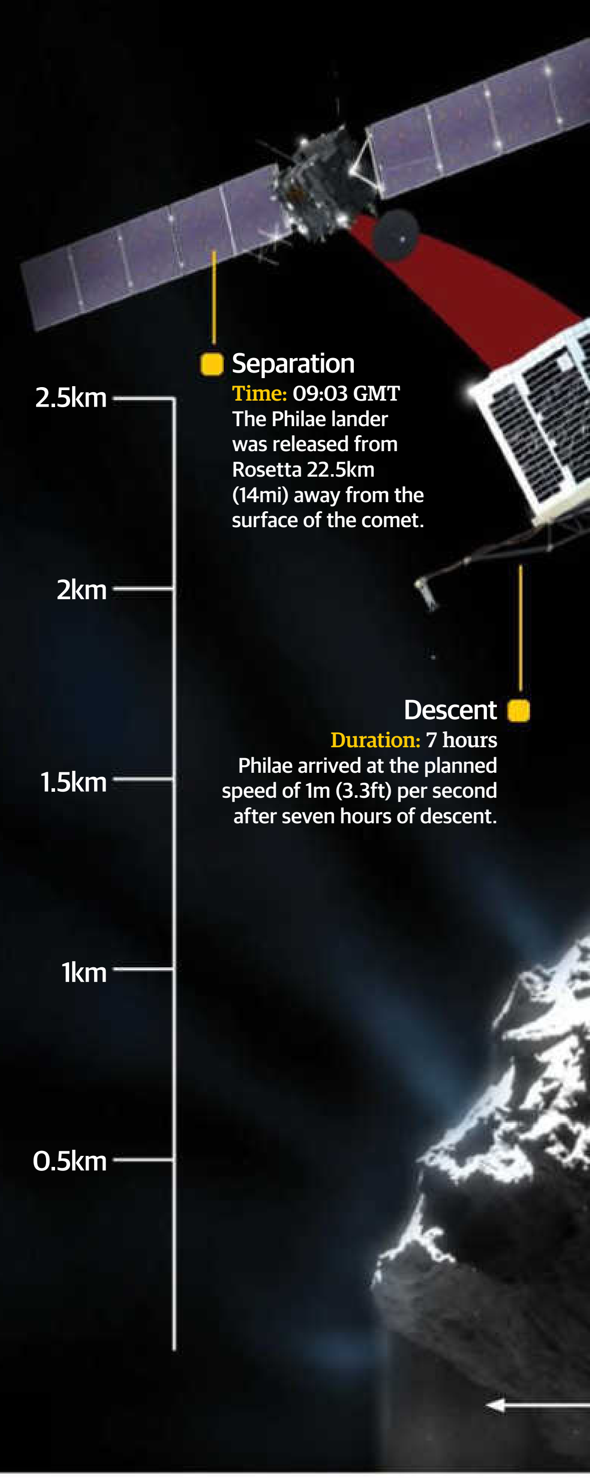
The anchoring harpoons did not fire and instead of landing safely, Philae bounced off, skipping twice like a stone before coming to rest. The surface of the comet was a dangerous combination of jutting rocks, boulders and plumes of gas and dust, and when Philae returned its first images, it became clear that it was tilted sideways in the shadow of a cliff with one of its legs up in the air. Having bounced away from its planned landing site, scientists on the ground had no idea where the probe had eventually touched down.

Without enough sunlight, Philae was in danger of running out of battery and in its precarious position, any manoeuvre could knock it over completely or worse, propel it out into space. However, despite these problems, Philae completed its first set of science experiments, providing an incredible wealth of new data.

Philae's primary batteries ran down after 57 hours, at which point it entered hibernation mode. But before it went to sleep, scientists tried a bold rescue operation. They lifted the probe by four centimetres (1.6 inches) and rotated it by 35 degrees in the hope that with the solar panels repositioned, it might be able to wake up as the comet gets closer to the Sun.



With very little gravity on the comet, Philae is about the same weight as a paperclip, and this image captured by its camera reveals its precarious position



3 Spirit rover

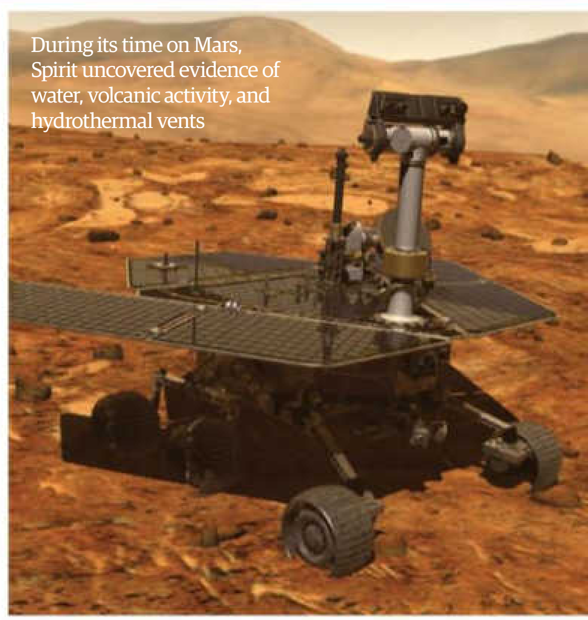
Disaster date: 1 May 2009
What happened: After five years on the surface of Mars, NASA's Spirit rover became lodged in a sand trap

In the spring of 2009, NASA's Spirit rover was investigating a location on Mars known as Troy, but the ground was softer than it appeared. In 2006 Spirit's right front wheel had stopped working, and as the top layer of soil gave way, the stuck wheel churned the ground and Spirit started to sink.

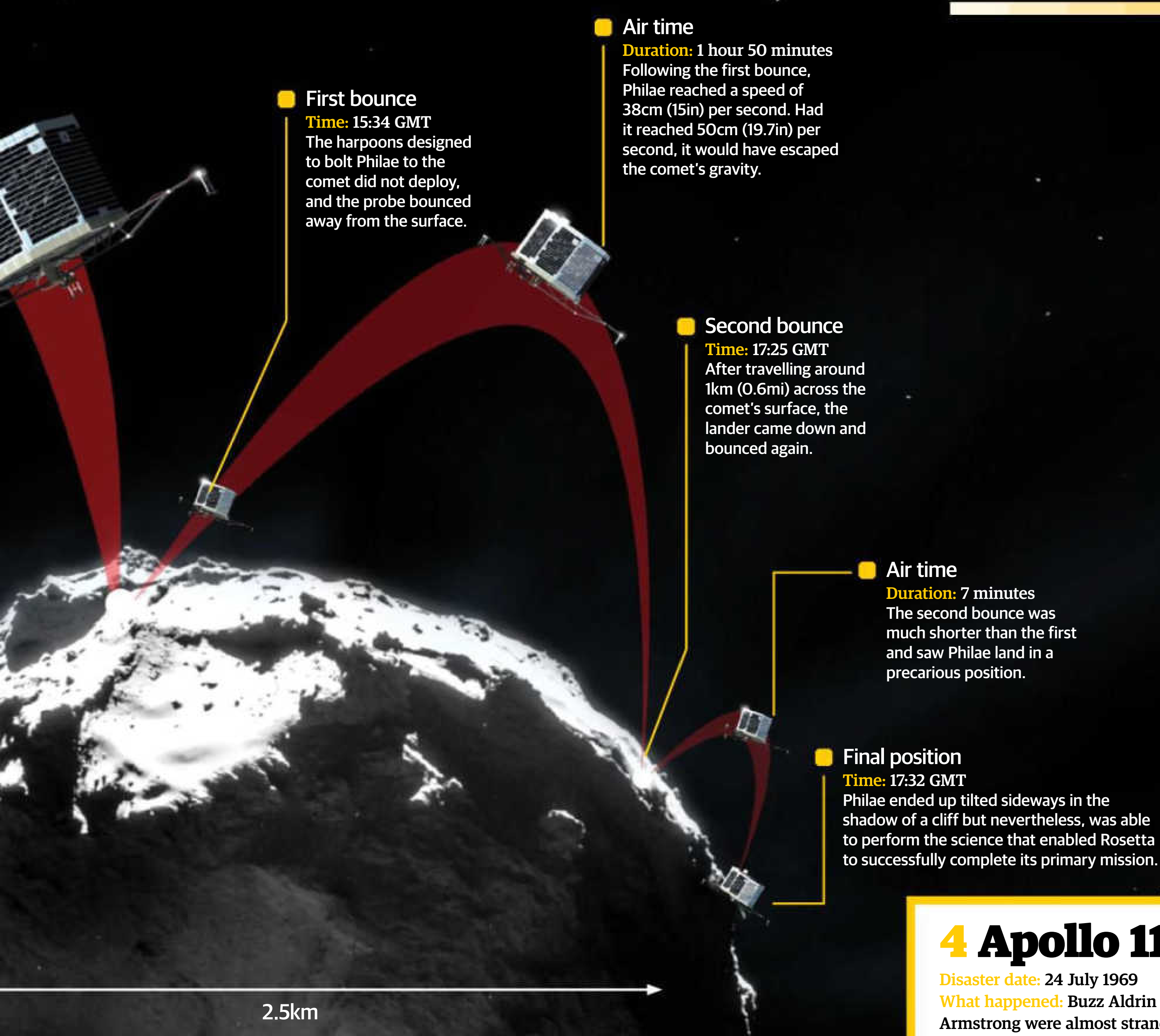
NASA engineers built a sandy testbed to replicate Spirit's predicament, and began testing different combinations of backwards driving and wheel wiggling to try to find the best way to free Spirit.

Attempts to rescue the rover began on 16 November 2009, but after three days it had only moved forwards by 12 millimetres (0.5 inches). The rear right wheel stalled repeatedly and after just a few attempts, it gave up altogether. With just four wheels remaining, and with winter fast approaching, the team feared that soon the rover would no longer be able to capture enough solar energy. They tried driving backwards, and managed to climb up for the first time, but progress was painfully slow and after eight months the rover was still trapped.

Winter eventually hit and Spirit entered hibernation, but unfortunately, contact never resumed. However, in the process of getting stuck churning up the soil, Spirit had released sulphates hidden beneath, revealing evidence of a nearby steam vent and providing new clues about the water cycle on modern Mars.



During its time on Mars, Spirit uncovered evidence of water, volcanic activity, and hydrothermal vents



The Spirit rover became stuck in soft soil at the edge of a crater, and despite months of rescue attempts was unable to break free

4 Apollo 11

Disaster date: 24 July 1969

What happened: Buzz Aldrin and Neil Armstrong were almost stranded on the Moon after the switch that armed their ascent engine broke

The Moon landing was one of the most monumental days in human history, but there were some tense moments along the way. The descent was challenging, and amid problems with communications and the on-board computer, Armstrong and Aldrin overshot their landing zone. They eventually touched down with less than 30 seconds of fuel remaining.

After their historic moonwalk, the two astronauts returned to the lander, but in the process one of their life support backpacks nudged the switch that armed the ascent engine and snapped it off. Without it, they wouldn't be able to return to the waiting orbiter. Ground control quickly replicated the fault on a mockup of the module on Earth, and set about finding a way to flick the switch using any available objects. Luckily, the astronauts were carrying pens, so Aldrin was able to use one to push the switch, arming the engine and saving the day.

Space Shuttle Endeavour carried seven crew members to Hubble and after five separate spacewalks, the telescope was fixed

5 Hubble Space Telescope

Disaster date: 20 May 1990

What happened: The iconic Hubble Space Telescope almost became one of science's biggest mistakes when it was launched into space with a faulty mirror

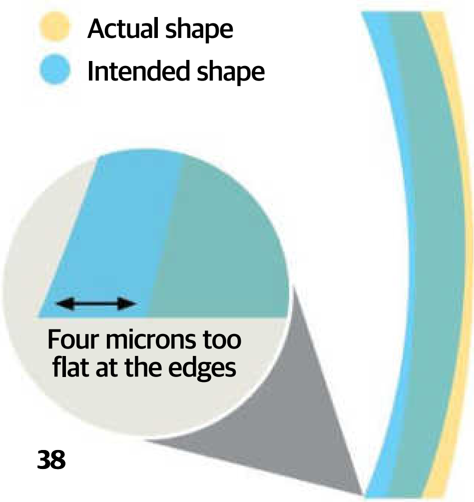
The Hubble Space Telescope has captured some of the most iconic images ever taken of outer space, but it started out with a major fault. The project had cost billions of dollars and carried a meticulously polished 2.4-metre (7.9-foot) mirror weighing just over 800 kilograms (1,800 pounds). Free from the interference of Earth's atmosphere, Hubble was expected to return high-resolution images but after the first images were returned just a few weeks later, it became clear that something was wrong.

The primary mirror had a flaw known as a spherical aberration; the edges were too flat, which meant that the light was not properly focused, causing a fuzzy halo to appear in every image. There was public outcry, and NASA came under attack for wasting money on a scientific disaster.

So, in 1993, NASA attempted to save the ailing space telescope. Seven crew members carried with them the Corrective Optics Space Telescope Axial Replacement (COSTAR). It was made up of five pairs of mirrors that, when installed in front of the Faint Object Spectrograph, the Goddard High Resolution Spectrograph and the Faint Object Camera, would work like a pair of glasses to bend the light, bringing it into focus. They also took the Wide Field Planetary Camera 2, which included its own corrective optics, and boosted Hubble's ultraviolet vision.

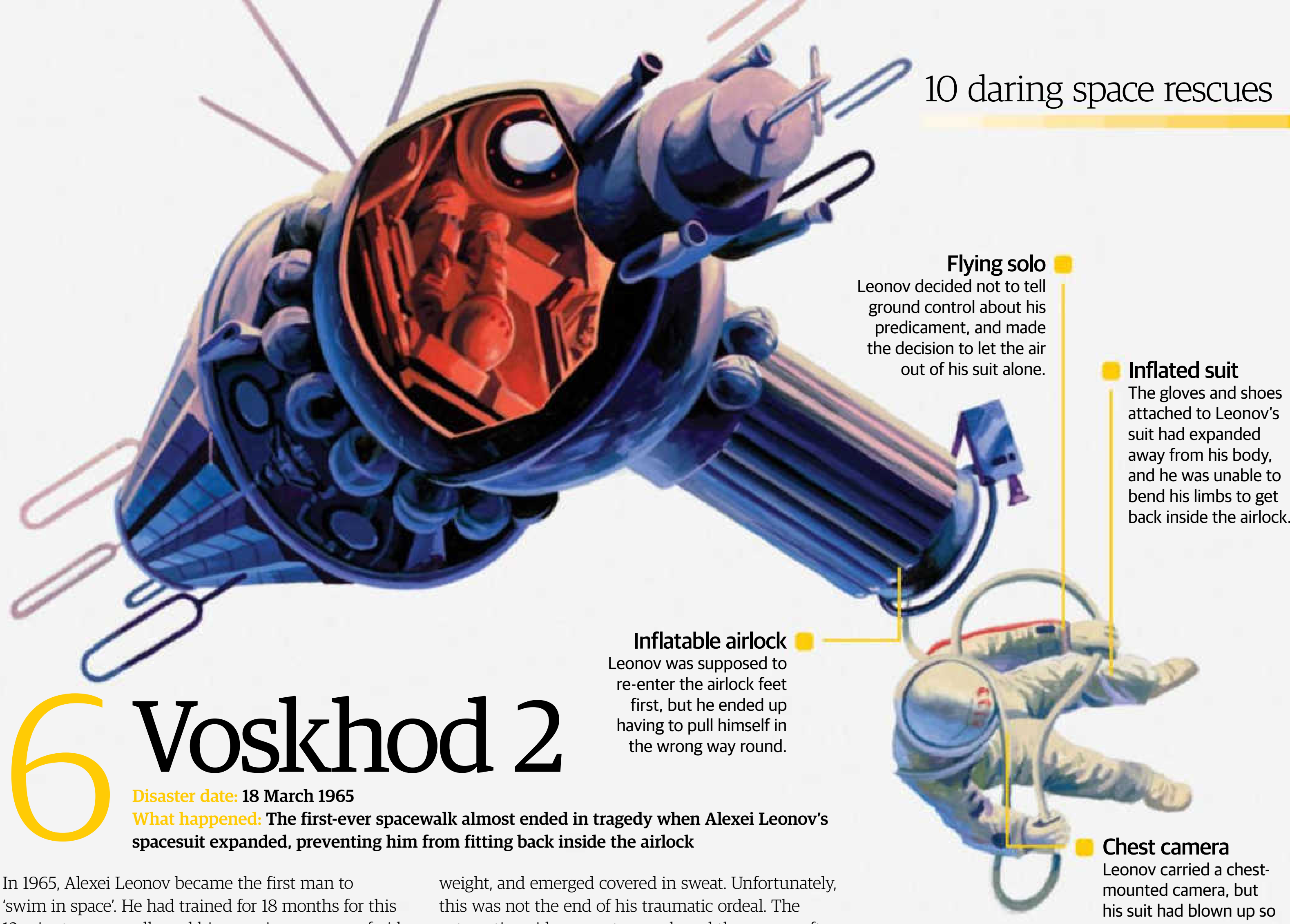
The astronauts spent 11 months training and practised the fiddly procedures over and over again inside a special water tank. The mission was a resounding success but during the final stages, while changing some insulation, a tiny screw floated away. Fearing that it could dent the new mirrors, the crew had to use the Shuttle's arm to capture it.

The mirror flaw



Spot the difference

This before and after image of the nucleus of the M100 galaxy reveals the full extent of Hubble's mirror fault



6 Voskhod 2

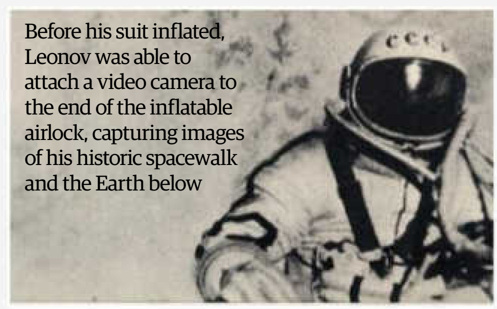
Disaster date: 18 March 1965
What happened: The first-ever spacewalk almost ended in tragedy when Alexei Leonov's spacesuit expanded, preventing him from fitting back inside the airlock

In 1965, Alexei Leonov became the first man to 'swim in space'. He had trained for 18 months for this 12-minute spacewalk, and his superiors were so afraid that something might go wrong that they reportedly provided him with a suicide pill in case he was unable to re-enter the spacecraft.

By the time Leonov had completed his spacewalk, the air inside his suit had expanded in the vacuum of space. Moving became difficult, and when he tried to return to the airlock he realised that he could no longer fit inside. Leonov was running out of time and realising the severity of his situation, he tried something brave. He began to deflate his suit, risking his oxygen supply by releasing the gas into space.

He managed to squeeze back into the airlock but in the process lost six kilograms (13 pounds) in body weight, and emerged covered in sweat. Unfortunately, this was not the end of his traumatic ordeal. The automatic guidance system on board the spacecraft was not working, so the crew needed to navigate re-entry into the Earth's atmosphere manually. As they descended the craft began to spin. They veered off course and came down in the icy wastelands of the taiga forests of Siberia.

The spacecraft eventually crash-landed in an area that was so inaccessible that the rescue helicopter was unable to land. Instead, they dropped supplies and the cosmonauts had to spend two nights in the forest with an open hatch, braving bears, wolves and the elements, before the rescue team accompanied them as they skied to the nearest landing point for evacuation.


Before his suit inflated, Leonov was able to attach a video camera to the end of the inflatable airlock, capturing images of his historic spacewalk and the Earth below


During a spacewalk on the ISS, water started to build up inside Luca Parmitano's faulty helmet, clinging to his eyes and nose

7 ISS helmet malfunction

Disaster date: 16 July 2013
What happened: An ISS spacewalk was abruptly cut short when Luca Parmitano's helmet started to fill with water

During a spacewalk on the International Space Station, Luca Parmitano realised that something wasn't right. He could feel water creeping across his communications cap, and it soon became clear that he needed to go back to the airlock.

As Parmitano tried to climb back, the Sun set, plunging him into almost total darkness. He later told us, "It's a black like nothing you can experience on Earth." Guided only by a 30-centimetre (12-inch) ring of light from his helmet and with water covering his eyes and nose, Parmitano had to navigate across a 'no-touch zone'. "I was upside down with no light, no eyesight because my eyes were covered, I had water in my nose and I tried to call the ground and Chris, but neither one could hear me."

Parmitano decided to return to the airlock unaided and five minutes later he was inside. "The next thing I knew Chris was squeezing my hand trying to get a response and my response was to squeeze as hard as I could to give him the okay."

8 Progress-Mir collision

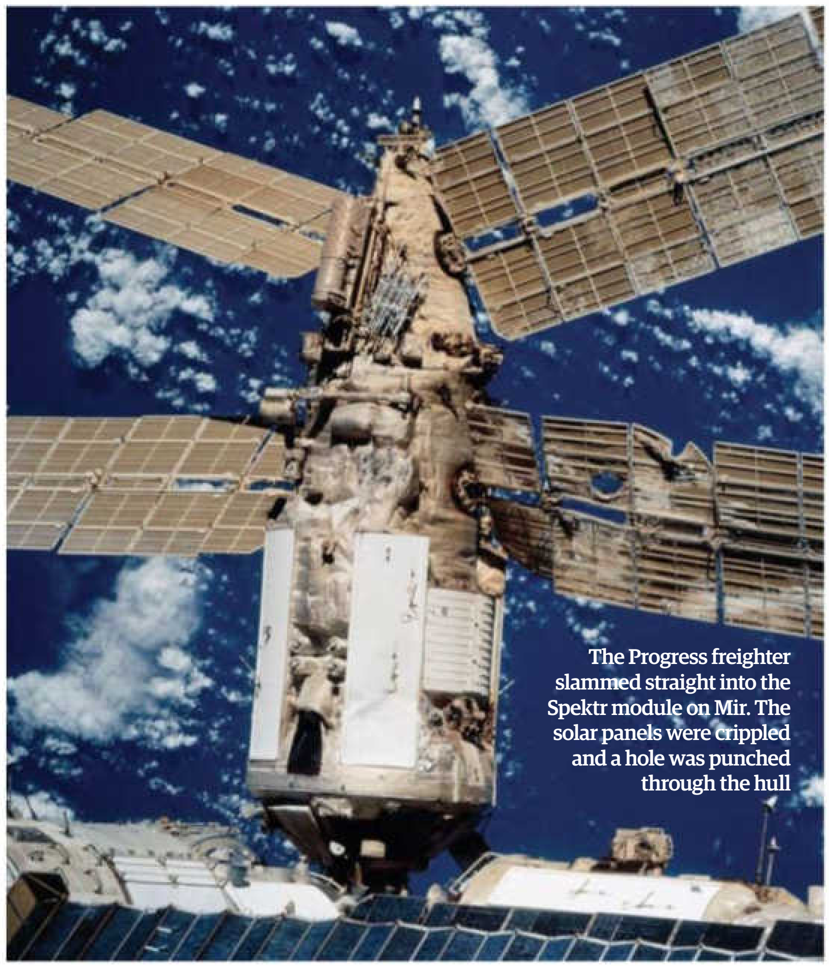
Disaster date: **25 June 1997**
What happened: **The crew of Mir faced catastrophe as a bus-sized supply freighter punched a hole in the Russian space station**

In 1997, Russian cosmonaut Vasily Tsibliev was in charge of docking the supply freighter Progress with the Mir Space Station. It was his job to guide Progress in, using an on-board camera to navigate. However, the slow pictures made judging the speed of the craft difficult and, as Progress headed towards Mir, it began to move too fast.

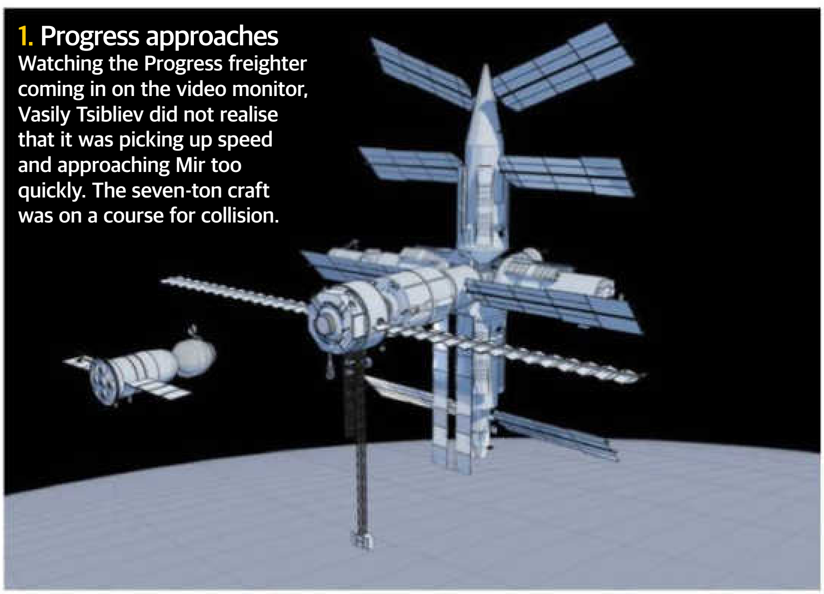
Cosmonaut Aleksandr Lazutkin saw the craft approaching and sounded the alarm. Even though Tsibliev had fired the braking rockets, it was too late and Progress slammed into Mir's Spektr module, crashing through the solar array and tearing a hole in the hull.

The crew worked rapidly to cut the connections to the damaged module. Pressure inside stabilised and the immediate danger was over, but the impact had set Mir spinning wildly, preventing the remaining solar panels from facing the Sun.

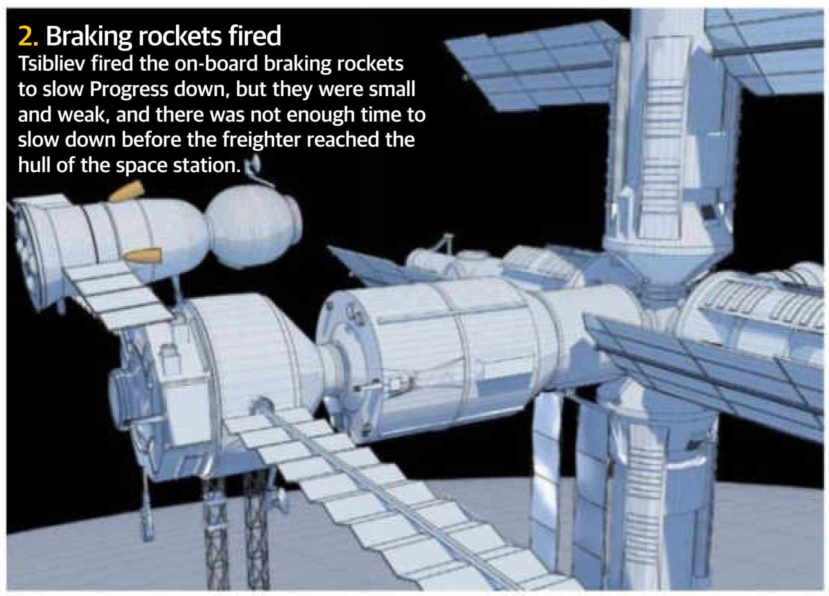
Working together with Tsibliev, who was now at the controls of the docked Soyuz, astronaut Mike Foale shouted instructions to fire the thrusters to bring the spin under control. As they passed over the sunny side of the Earth, they managed to charge the batteries and to the relief of all, the space station came back to life.



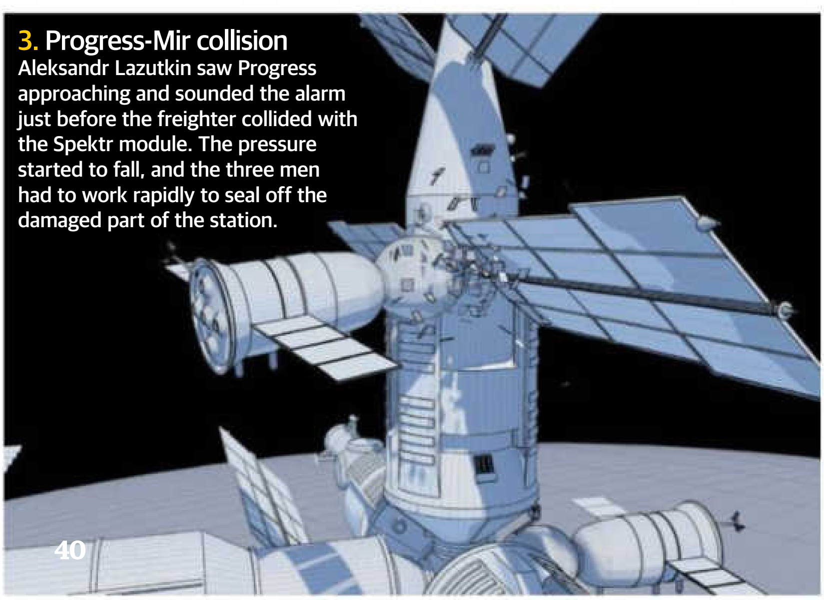
The Progress freighter slammed straight into the Spektr module on Mir. The solar panels were crippled and a hole was punched through the hull



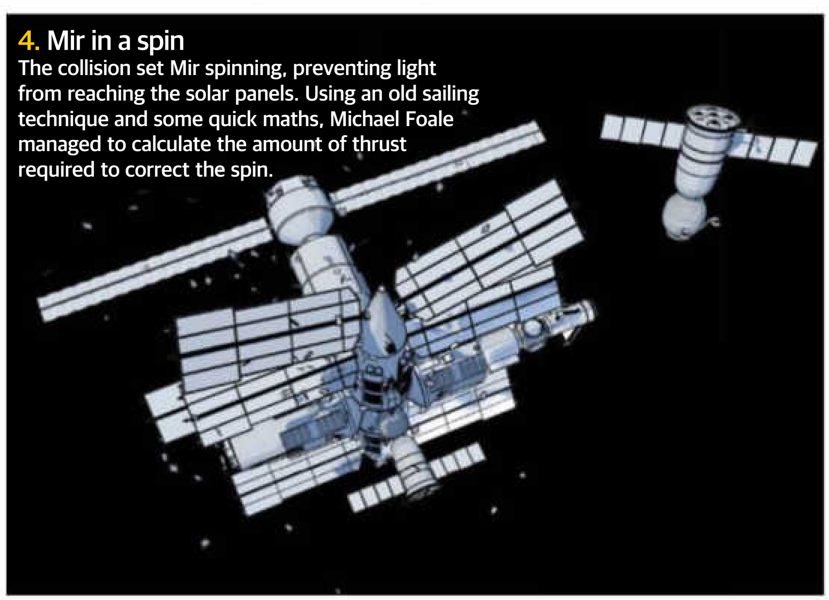
1. Progress approaches
Watching the Progress freighter coming in on the video monitor, Vasily Tsibliev did not realise that it was picking up speed and approaching Mir too quickly. The seven-ton craft was on a course for collision.



2. Braking rockets fired
Tsibliev fired the on-board braking rockets to slow Progress down, but they were small and weak, and there was not enough time to slow down before the freighter reached the hull of the space station.



3. Progress-Mir collision
Aleksandr Lazutkin saw Progress approaching and sounded the alarm just before the freighter collided with the Spektr module. The pressure started to fall, and the three men had to work rapidly to seal off the damaged part of the station.



4. Mir in a spin
The collision set Mir spinning, preventing light from reaching the solar panels. Using an old sailing technique and some quick maths, Michael Foale managed to calculate the amount of thrust required to correct the spin.

9 Space Shuttle Discovery

Disaster date: 26 July 2005
What happened: **During the launch of the first Space Shuttle flight after the 2003 Columbia disaster, the heat shielding on the underside of the craft was damaged**

The crew had to fix the heat shield problems before returning to Earth

In 2005, NASA's Space Shuttle Discovery travelled to the International Space Station to deliver supplies and equipment, but during launch the craft sustained some damage. Several chunks of insulating foam broke away from the Shuttle, and some of the ceramic gap fillers that stop the heat shield tiles from rattling managed to wriggle free. Engineers were concerned that these uneven bumps would cause turbulence as the craft re-entered Earth's atmosphere, and projected that the damage could increase heating by up to 30 per cent, potentially putting the lives of the crew in danger.

Just two years earlier, Space Shuttle Columbia had broken up on re-entry following damage to its heat shields, tragically ending the lives of its seven crew members. After this tragedy, ground control was not happy to allow the Discovery crew to return to Earth until the damage had been fixed.

A repair mission was included during the third and final spacewalk, but nothing like it had ever been attempted before. The underside of the Shuttle was fragile and astronauts had never been allowed so close to the heat shielding tiles before. As a consequence, no handrails had been built in for support, so astronauts Steve Robinson and Soichi Noguchi had to ride on the International Space Station's Canadarm2 robotic arm to reach the damaged area.

Robinson was to perform the historic repair and he carried a pair of forceps and a saw with him, in case the ceramic fabric was difficult to remove. But in the end he found it simple enough to ease them out with his fingers. As he triumphantly removed the second piece he said, "it looks like this big spaceship is cured". The Shuttle was later cleared for re-entry, and returned safely to Earth on 9 August 2005.

> "Ground control wouldn't let Discovery return to Earth until the problem was fixed"

NASA astronaut Steve Robinson captured this close-up image of Discovery's heat shields as he performed the vital repairs

10 Liberty Bell 7

Disaster date: 21 July 1961
What happened: **One of the first-ever suborbital space flights almost ended in disaster when the escape hatch blew open prematurely, flooding the capsule in the middle of the ocean**

Gus Grissom had been on a 15-minute suborbital flight and had splashed down in the Atlantic Ocean. His capsule, Liberty Bell 7, was fitted with a new explosively activated escape hatch at the side but as he waited for the helicopter, it burst open and water flooded in. Grissom escaped as the capsule started to sink but he was left floating in the open ocean. He had also forgotten to close the oxygen inlet to his suit and water was trickling in, weighing him down.

Unaware of his immediate peril and thinking that the spacesuit would keep Grissom afloat, the helicopter pilot attempted to rescue the sinking capsule first. But Liberty Bell 7 kept refilling as the waves swelled, and the helicopter could not take the strain.

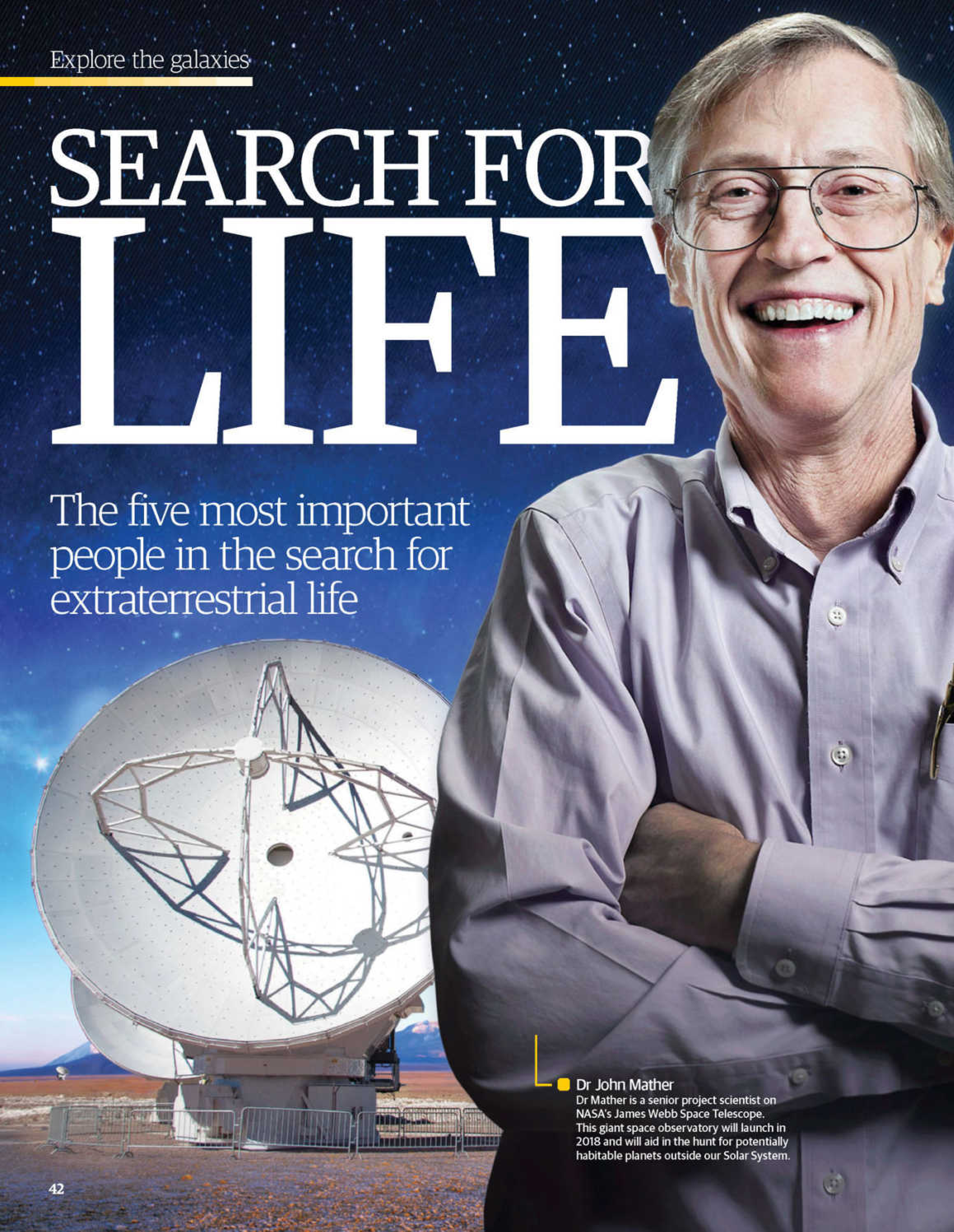
After a tense four minutes and with Grissom close to drowning, the sinking capsule was abandoned to the waves, and a second helicopter was called to pluck the exhausted astronaut from the water.

The hatch on Liberty Bell 7 flooded with water each time the waves swelled, and the helicopter's engine almost cut out

With the first helicopter in a bad way, a second rescue pilot had to be called to pull Grissom from the Atlantic Ocean

SEARCH FOR LIFE

The five most important people in the search for extraterrestrial life



Dr John Mather
Dr Mather is a senior project scientist on NASA's James Webb Space Telescope. This giant space observatory will launch in 2018 and will aid in the hunt for potentially habitable planets outside our Solar System.

Dr Jerry Ehman
Dr Ehman, now retired, is an American astronomer. He previously worked for SETI and in 1977 he discovered the famous Wow! signal, which just might have been our first contact from an intelligent alien race.

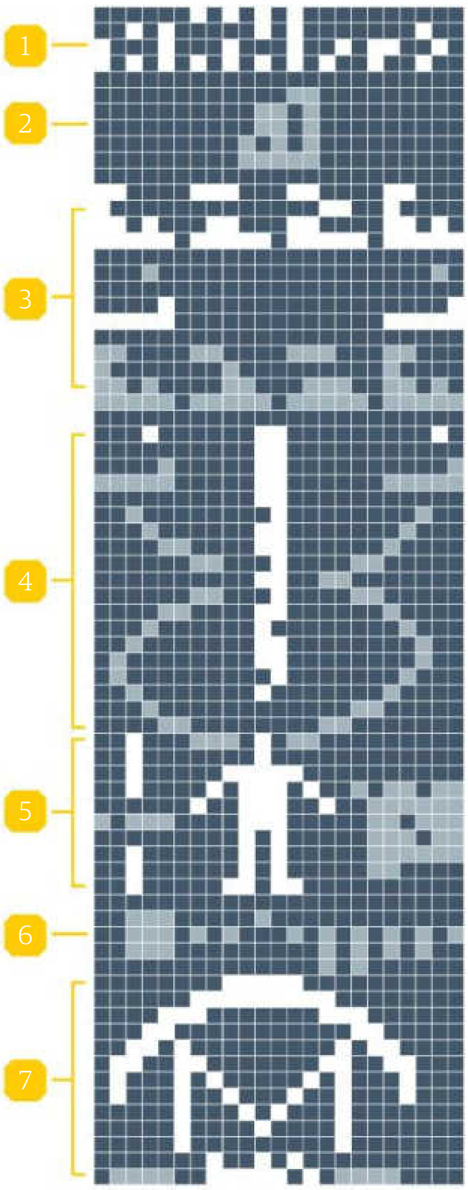
Dr John Elliott
Involved with SETI since 1999, Dr Elliott's research includes working out how we'd decipher and respond to an alien signal. He is a Reader in Intelligence Engineering at Leeds Metropolitan University in the UK.

Dr Seth Shostak
As senior astronomer at the SETI Institute in Mountain View, California, Dr Shostak is actively involved in the hunt for intelligent life. He is also a writer and hosts the *Big Picture Science* radio show.

Dr Jennifer Eigenbrode
Dr Eigenbrode is a biogeochemist at NASA who specialises in astrobiology. She's looking for signs of life in the smallest places, including looking for biosignatures in rocks and ice on Mars through the Curiosity rover.

The Arecibo message

On 16 November 1974, astronomers including Dr Frank Drake and Carl Sagan devised a message to send into the distant reaches of space. The message was intended to show the possibilities of communication with a potential intelligent race, rather than actually attempting to make contact.



1. Numbers
The numbers one to ten written in binary.

2. DNA
These represent the atomic numbers of the elements that make up DNA.

3. Formula
These are the formulas for the sugars and bases in DNA.

4. Double helix
A graphic of the double helix structure of DNA.

5. Population
A figure of a human and Earth's population.

6. Solar System
A graphic depicting the Solar System.

7. Dish
A graphic of the Arecibo dish and its dimensions.

Every month we hear of incredible new exoplanets in planetary systems seemingly like our own, and we learn more in the search for past or present microbial life as missions like Curiosity gain worldwide attention, but for some reason the notion that we might be just one intelligent race among many is yet to receive much support from the public at large.

Many people today still seem to have the same opinion that was prevalent in the mid to late 20th Century, that aliens are something that belong only to the realm of science fiction, but this is in the face of overwhelming evidence to the contrary. With every passing year, every new discovery of an exoplanet, every observation of frozen or liquid water on other bodies in the Solar System, it becomes harder and harder to argue that we are alone in our galaxy, let alone the entire universe.

In fact, it's a position that even notable astronomers are taking up. "We can't be the only instance of a race, we just can't be," said the late Sir Patrick Moore when talking to us in 2012, and he is joined by many others around the world who are coming around to the realisation that to think humanity is the only instance of intelligent life is implausible, ignorant and just plain naive.

For about half a century we have begun to seriously consider the possibility that we are not alone, and to prove this hypothesis scientists have focused on three areas of research, each equally capable of becoming the first to discover life outside of the confines of Earth. Throughout this feature we've spoken to the five most important people within these fields to find out what progress they're making in the search for life.

The first is the Search for Extraterrestrial Intelligence, or SETI, which is a privately funded international endeavour to discover signals from an alien race drifting through the cosmos. Next is the search for exoplanets (worlds outside our Solar System), an area of research that has only gained credence in the last couple of decades. The field of planet hunting may be young, but it is already providing us with fascinating results that may soon help us find an exoplanet just like Earth. The final area of research is the search for microbial life, fossilised or alive, on other worlds inside our Solar System. Until now this has largely focused on Mars, but places like Europa and Titan could also prove fruitful to explore.

The oldest of the three areas of research is SETI, using antennas around the world to look for alien signals. In 1959, Giuseppe Cocconi and Philip Morrison, two physicists from Cornell University in the USA, suggested for the first time that it might be possible to communicate with another intelligent race among the stars using microwave radio. "The probability of success is difficult to estimate," they wrote in the journal Nature, "but if we never search, the chance of success is zero."

At around the same time a young radio astronomer named Frank Drake came to the same conclusion, and in the following year he used a 26-metre (85-foot) telescope in West Virginia, USA, to conduct the first search for alien signals outside our Solar System. He found nothing, but his research (including the Drake equation, which estimates that the chances of life elsewhere in the universe is almost a certainty) sparked an interest around the globe that remains prevalent to this day. It was in fact the Soviet Union in the Sixties that first dominated SETI, observing huge portions of the sky at once. They were sure that there would be many advanced civilisations emitting

> "We can't be the only instance of a race, we just can't be" **Sir Patrick Moore**

The Arecibo Observatory in Puerto Rico

He'll be the person to know first

Dr Seth Shostak

How do you guys analyse incoming data at SETI?
The data analysis is all pretty automatic. Unless there's a signal that's looking very promising, and that only happens every couple of years, then you don't actually deal with the data processing. The algorithms in the software analyse them and do rather simple tests to try to prove if it's really ET, or if it's AT&T – interference from a telecommunications satellite or whatever.

Are there protocols in place for announcing the discovery of an alien signal?
We've been worrying about the protocols about what to do if we find a signal. We've rewritten them and they're all very nice in a nice little document, but the reality is that nobody's going to pay a whole lot of attention to protocols if we pick up a signal. And we know that because we've had false alarms, like in 1997 when for almost a day it looked like we had a signal that was the real deal. And did people stick to protocols and say, 'well, we've got to notify these people and those people?' No! None of that happened. It was completely chaotic, which it would be.

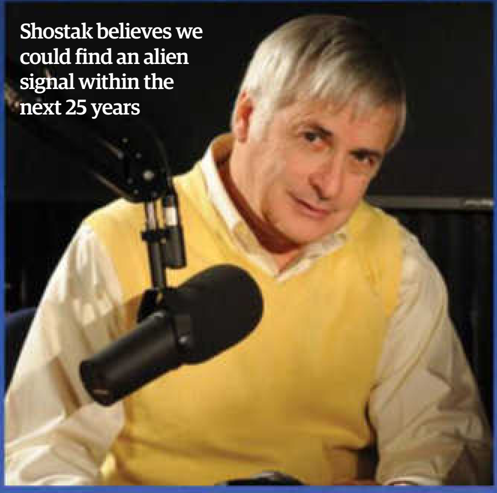
What's the next step after the discovery of a signal?
If you get a signal that looks like it might be ET on the line, the first thing you do is to spend an awful lot of effort trying to verify that, maybe several days. But in all that time while you're doing this there's no policy of secrecy, so lots of people know you've got an interesting signal. In 1997, when we had this promising signal there were no men in black, the government hadn't the slightest interest in any of it, but the media did and they started calling me up.

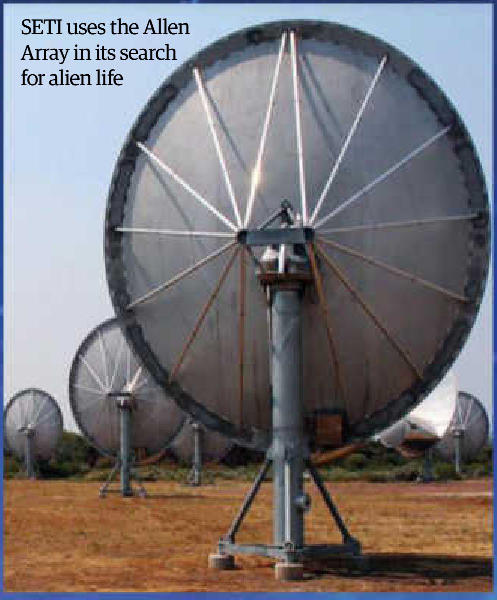
What happens next?
After that, every telescope in the world would be aimed in the direction of the signal to try to find out how far away it is and whether there are planets there. Keep in mind that the instruments [being] used by SETI are not capable of [deciphering] messages. You're getting the bottle [signal] without the message in it, but at least you've got the bottle so you know that somebody's trying to say something.

What would become of SETI?
There would suddenly no longer be a fight to try to get enough money to keep doing the SETI experiment. There would be enough money to build much bigger instruments and go back and possibly find any message. I'm sure there would be a message there. I think that immediately SETI would be vaulted from sort of a backburner niche science experiment to something that many, many people were doing. That's exactly what happened with the discovery of planets around other stars. There were a couple of guys doing it in the world, and suddenly it became an industry. That's what would happen with SETI.

Would we understand the message?
My guess is they're likely to be hundreds of thousands of years, maybe more, beyond us. And for us to understand the information content of their transmissions is probably asking too much. But at least you'd know they were there, and that's really the idea, isn't it? You would know that what we have here on Earth is pretty nifty, but it's not a miracle.

Are you confident we'll find a signal?
I bet everyone here a cup of coffee that we'll find aliens within two dozen years.

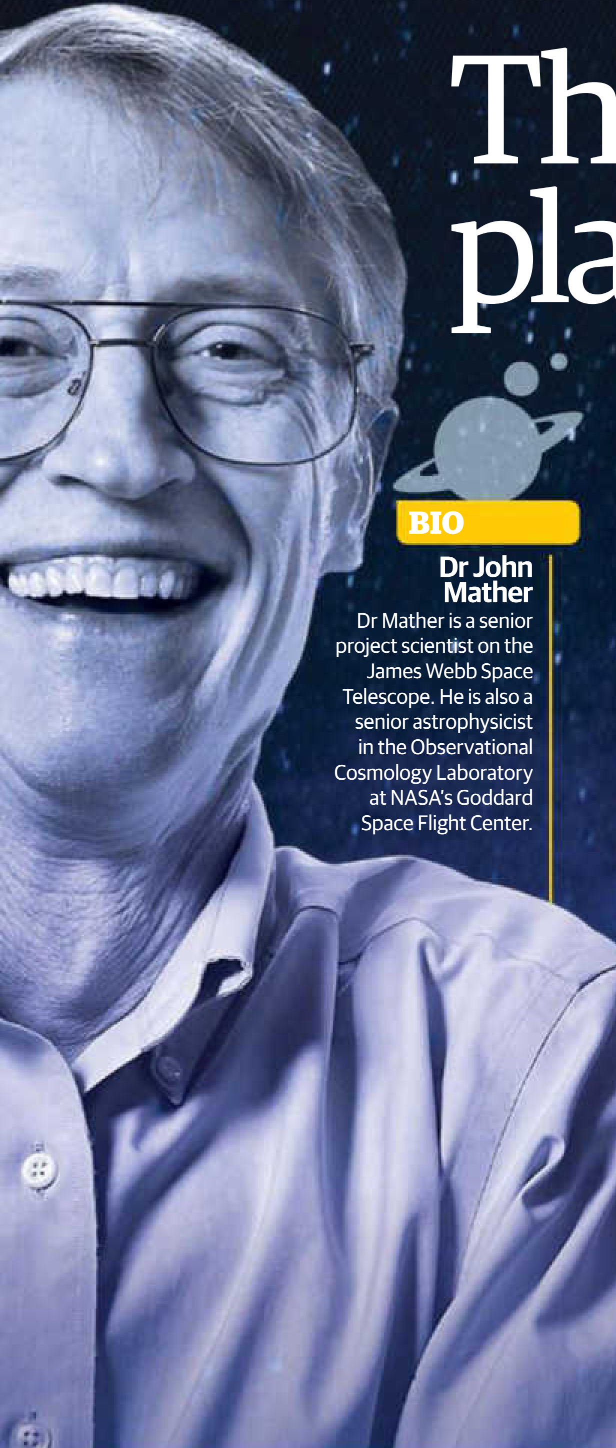

Shostak believes we could find an alien signal within the next 25 years


SETI uses the Allen Array in its search for alien life

BIO

Dr Seth Shostak
Dr Shostak is the senior astronomer for the SETI Institute in Mountain View, California. He is actively involved in the hunt for alien signals. He is also a writer and hosts a weekly science radio show.

"In 1997, for almost a day it looked like we had a signal, that was the real deal"



The next great planet hunter

Dr John Mather

BIO

Dr John Mather

Dr Mather is a senior project scientist on the James Webb Space Telescope. He is also a senior astrophysicist in the Observational Cosmology Laboratory at NASA's Goddard Space Flight Center.

What's your role on the James Webb Space Telescope (JWST) project?
I'm the senior project scientist, which means that I work with the project management and engineering teams to define the mission requirements to make sure that they are correctly implemented, and with the scientific teams to make sure we have understood the scientific opportunities and their implications for what should be built to enable spectacular discoveries.

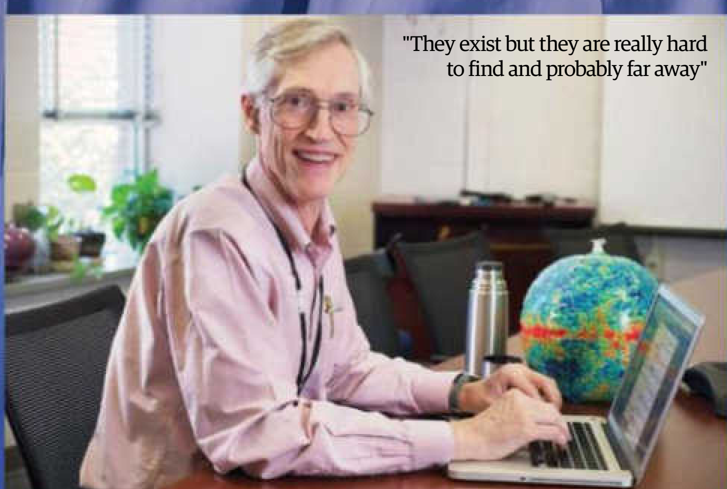
What work will you be doing in the coming years, and post launch in 2018?
I'll be continuing my role as senior project scientist to make sure our mission realises its potential. Post launch I anticipate writing observing proposals and working with colleagues to write up the results. I hope to be lucky and find something that's a great surprise.

How will JWST aid in the hunt for exoplanets?
We have two main ways. First, we look at planets directly with coronagraphs in three of the four instruments. Coronagraphs block out the direct starlight so we can look for planets orbiting nearby, which is primarily valuable for large and young planets. Second, we watch a star get fainter when a planet goes in front of or behind its star [which is known as 'transiting']. We can get amazing details about the planets and their atmospheres from this data.
The Kepler mission has given us thousands of candidate planets [using the transiting method] and they are all interesting. If we can get a really good target there is the possibility that we could find signs of water around a large version of Earth, and then we would think such a planet could harbour life.

Could a separate star shade be flown near the James Webb Space Telescope to block out the light of distant stars and help find planets?
Yes, of course! Our team considered star shades in the very early days of conceiving the mission, but the technology was clearly not ready in 1996. Now, much work has been done by university groups and aerospace firms like Northrop Grumman and Lockheed Martin, and we know quite well how to design such a shade. In my opinion it could be done for a budget that would be worth the fabulous planet measurements that could be made. Either a star shade could be built to fly near to JWST, or a star shade could be made to work with a new telescope. Both are difficult but possible.

Do you think we'll find an Earth-replica before JWST launches in 2018?
Yes, I think the Kepler mission will find planets a lot like Earth, in the sense of being the right size and temperature, orbiting stars a lot like the Sun. But we probably won't know much about their properties, so we won't be able to say they are 'exactly' like Earth.

Do you think we will ever make contact with an intelligent alien race?
I don't think we will make contact with an intelligent extraterrestrial race any time soon. I think they exist but they are really hard to find and probably far away. On the other hand, I really do think it's worth trying! We already have technology that could send detectable signals across our whole galaxy, but it would only work if somebody on the other end knew how to receive them. Now our job is to guess how to eavesdrop on those other civilisations, if they exist.



"They exist but they are really hard to find and probably far away"

The James Webb Space Telescope is set to launch in 2018

Did he already make contact?

Dr Jerry Ehman

What are you working on at the moment?
I am retired. I enjoy bowling and golf and am involved in church activities. I unvolunteered from the Ohio State University Radio Observatory back in 2008, so I am no longer actively working much in SETI.

What were you doing at the time you discovered the Wow! signal?
I was a professor in Management Science at another university in Columbus, Ohio. I was also a volunteer at the Ohio State University Radio Observatory (OSURO).

What was the Wow! signal?
It was a strong narrowband signal from an unknown object. The distance to that object could not be determined.

Did you believe the Wow! signal was a sign of extraterrestrial intelligence?
Since all of the possibilities of a terrestrial origin have either been ruled out or seem improbable, and since the possibility of an extraterrestrial origin has not been able to be ruled out, I must conclude than an extraterrestrial intelligence *might* have sent the signal that we received as the Wow! source.

Where do you think it came from?
After some analysis and thought, it became quite obvious that this signal came from some object a large distance away from the Earth (well beyond the distance of the Moon).

Could we have learned more about the signal if more resources had been available?
At the time, personal computers didn't exist. If we had today's equipment, much more could have been learned. For example, it might have been possible to detect the modulation [information] components of the signal.

Do you think we'll detect a signal from an intelligent race in the coming years?
I'm certainly hopeful.

Will we ever contact alien life?
Contact is less likely than the detection of a signal, although I'm also hopeful that contact will occur some time in the next billion years or so.

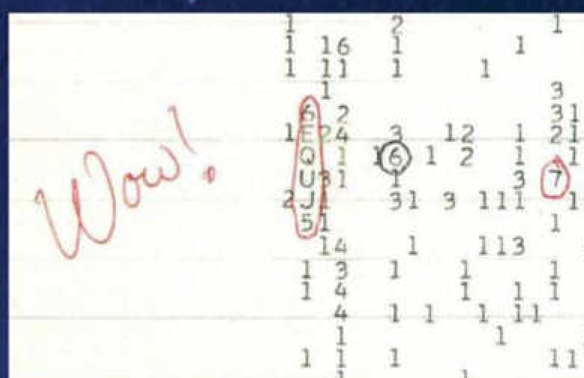
Do you think life is out there?
Absolutely!

BIO

Dr Jerry Ehman
Dr Ehman, now retired, is an American astronomer. He holds a PhD in astronomy from the University of Michigan. In 1977, while working on the Big Ear radio telescope at the Ohio State University, he discovered the famous Wow! signal.

The Wow! signal

One of the most famous instances of the detection of possible alien life was a radio signal that has been dubbed the Wow! signal, owing to Jerry Ehman (above) circling the signal in excitement. Ehman discovered the signal on 15 August 1977 while working on a SETI project. The circled code, '6EQUJ5', indicated an increased intense signal that seemingly came out of nowhere.



huge amounts of power that would be easy to spot, but this was not so.

It was widely believed that SETI had a good chance of success, though, so in the Seventies NASA threw its hat into the ring. It established SETI programmes in California at its Ames Research Center in Mountain View and the Jet Propulsion Laboratory in Pasadena to look for signals around stars like our Sun or otherwise. In the mid-Nineties, however, funding was cut, and the SETI Institute was forced to go it alone.

SETI uses a number of antennas and arrays around the world, such as the Allen Telescope Array in California, to observe distant stars and discern whether they are emitting any artificial signals produced by an intelligent race. Within minutes of observing a star they have an answer, but to this day they have yet to find any conclusive evidence of extraterrestrial intelligence. Undeterred, workers at SETI continue to search for signs of life, and they're extremely confident that they will find something.

To aid in SETI's study, the hunt for habitable exoplanets might allow us to find worlds where life could reasonably be thought to reside. Finding habitable exoplanets that SETI can study for signals is something that will prove of great importance. Of course, planet hunting itself is an area of astronomy that is not even two decades old – the first exoplanet was not discovered until 1995. But while planet hunting might still be in its infancy, the results we have obtained from just a handful of telescopes are astounding. NASA's Kepler space telescope, which launched from Cape Canaveral in March 2009, has found thousands of planet candidates in barely four years of operations, and some of these offer tantalising hints of being habitable.

But Kepler is looking at just a tiny portion of our giant Milky Way, which in turn is relatively small in the grand scheme of the universe. Based on data from Kepler, astronomers at the Harvard-Smithsonian Center for Astrophysics estimated in January 2013 that there were at least 17 billion Earth-sized exoplanets in the Milky Way. That's not a typo; billion, not million. Consider that there are about 100 billion galaxies in the known universe, and things start to get really exciting. Is it really possible that, out of 1.7 trillion trillion potential planets in the 13.7 billion-year-old universe only one, Earth, had the necessary conditions to produce intelligent life? Many leading scientists believe this to be unlikely.

Kepler, however, can only reveal very basic data about an exoplanet, including its size, mass and orbit. Future telescopes, like NASA's James Webb Space Telescope, will allow us to study these planets in even more detail. This giant space observatory, which will launch in 2018, might be able to directly image exoplanets and even reveal the composition of

Dr Eigenbrode believes that if alien life exists beyond Earth it is most likely microbial

Looking for life in small places

Dr Jennifer Eigenbrode

What's your role at NASA?
I am a research scientist at NASA Goddard Space Flight Center. My studies focus on understanding the sources, alteration, and preservation of organic molecules in geological materials on Earth and Mars. I am a participating scientist on the Mars Science Laboratory [Curiosity] and a collaborator for the Sample Analysis at Mars [SAM] instrument suite that can detect organics in Gale Crater sediments.

Do you think we'll find evidence of past or present life on Mars?
I think Mars may have harboured life in the past. The conditions of Mars 3.5 billion years ago were probably similar to the conditions of Earth. Both were likely habitable. If past life did exist on Mars, then there should be a record of it in the sediments. If life didn't exist on Mars, we may expect to find meteoritic or geological organic matter. Hopefully, we'll find preserved organics in the surface sediments at Gale Crater where the MSL rover is exploring. Exploration by the ESA/NASA ExoMars rover [due to land in 2018] and the NASA Mars 2020 rover will be valuable in furthering our understanding of organic preservation on Mars.

Where else could we find organics in the Solar System?
Today, we find evidence of organics in interstellar gas particles, meteorites, comets and in some planetary atmospheres [such as methane on Mars and Titan]. There is every reason to suspect that organics have been distributed all over the Solar System. What we do not understand is what has happened to these organics since their initial distribution. What processes have altered them? Has life tapped their carbon and energy to support extraterrestrial ecosystems?

Curiosity is currently searching for signs of life on Mars

Do you think the Allan Hills 84001 meteorite contained fossilised life?
It was the publication of the suspected microfossils in this Martian meteorite that energised the field of exobiology [now astrobiology]. As much as I wanted to believe 84001 contained Martian microfossils, I was never convinced.

Will we find more complex forms of life in the Solar System?
If life exists elsewhere in the Solar System, it is most likely microbial in nature. Micro-organisms and the communities that they form can be complex, but I do not think that macro-organisms or intelligent life evolved in the Solar System. Micro-organisms can harbour and manipulate small niches on planets. Larger organisms need a larger environment for support. Most environments we have observed beyond Earth do not seem conducive to supporting the physics and chemistry of macro-life forms.

What future astrobiological missions could be of most interest?
Of all the places for us to explore for possible past or present extraterrestrial life, Mars offers our best opportunity to find it. It's close and the environments are similar enough to Earth's that we can figure out how to best explore them. Exploring extremely unfamiliar environments is equally important to astrobiology. Venus, Titan, Europa and other bodies in the Solar System have conditions that are so different from Earth's that they challenge us to think outside of the box, which will also provide us with an observational baseline for exoplanet comparison.

Which do you think will be first to find signs of extraterrestrial life: robotic exploration, planet hunting or signal detection (SETI)?
I think robotic exploration poses our best chance of observing signs of extraterrestrial life since most life beyond Earth is probably microbial, if it exists.

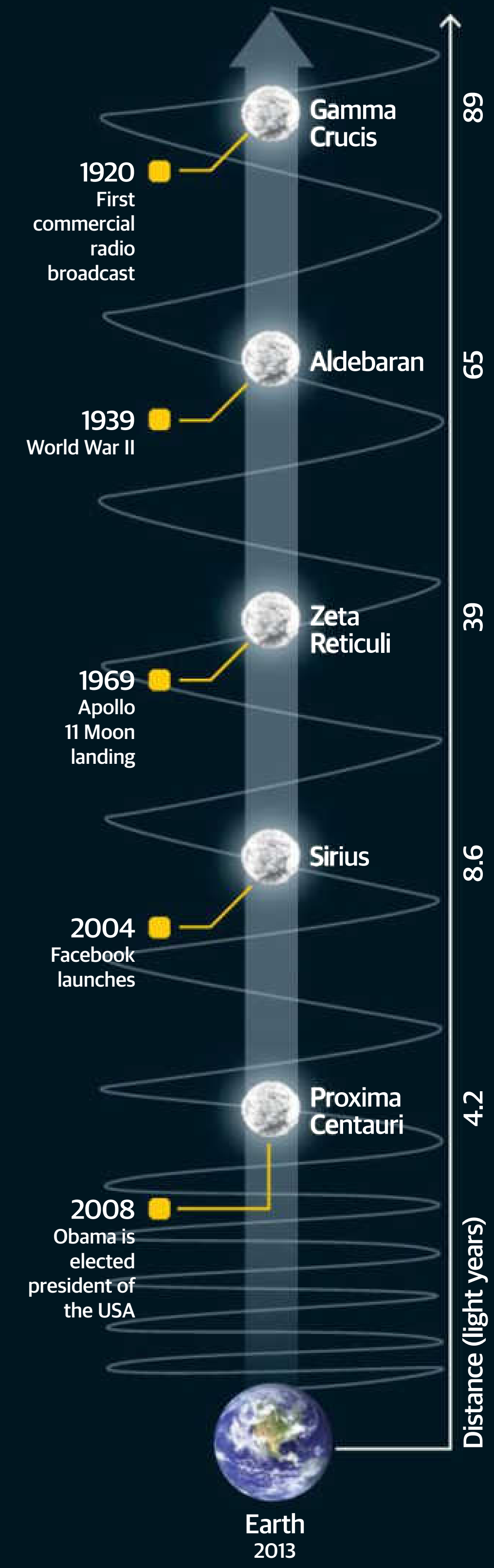
BIO

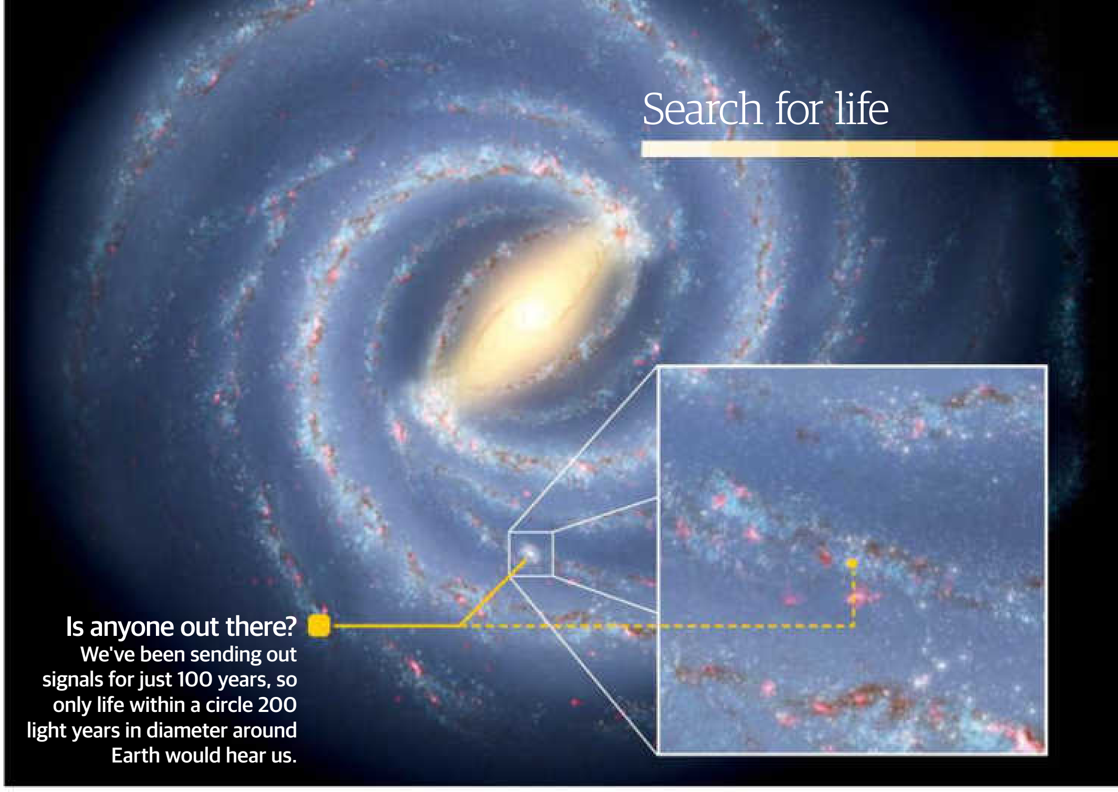
Dr Jennifer Eigenbrode
Dr Eigenbrode is a research scientist at NASA Goddard Space Flight Center, who specialises in astrobiology. She is also a participating scientist on the Mars Science Laboratory mission.

"Robotic exploration poses our best chance of observing signs of extraterrestrial life"

Interstellar broadcasts

For the past 100 years we've been broadcasting our position to the rest of the galaxy, but how far have our signals actually reached?





their atmosphere, a vital clue in discerning whether they are habitable or not. Groundbreaking research into the possibility of measuring the atmospheres of exoplanets for signs of methane, oxygen and other elements, or even looking for signs of artificial lights (just as we can see the Earth at night from space) will bring us closer to finding alien civilisations.

While we're searching for alien life, however, could it be possible that other extraterrestrial races are also doing the same thing? We've been broadcasting our position, both intentionally and unintentionally, by emitting radio waves for about a century. If anyone is within 100 light years of Earth, they will be able to hear us. In fact, in 1974 we sent out something called the Arecibo message, a broadcast of radio waves that, for the first time, contained data about humanity that could be interpreted by an alien race and understood to be a call from our civilisation to theirs. It's not inconceivable to think that other races might have done the same thing; maybe there are thousands of Arecibo messages streaming through the galaxy, but we just haven't come across one yet.

With all this talk of exoplanets, habitable worlds and aliens, however, you might be forgiven for having one question burning in your mind; if there really is intelligent life out there, then where is everyone? You're not alone in thinking this. Way back in 1950, astrophysicist Enrico Fermi asked this very question, which became known as the Fermi paradox. He argued that because the galaxy isn't teeming with spacecraft, or that we've never been sent a message from aliens, then either interstellar travel must be impossible (therefore dashing our hopes of ever exploring the galaxy) or we are the only intelligent civilisation in the universe.

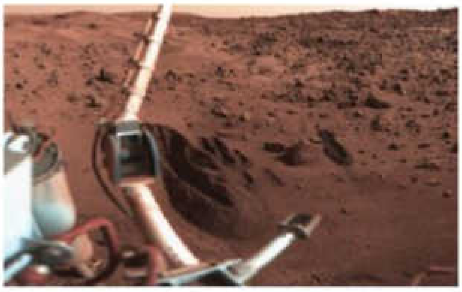
There are a number of explanations as to why this is so, but the most plausible relates to the history of a planet like Earth. Our planet is 4.6 billion years old, but only in the last several hundred million years has it been inhabited by sophisticated organisms. Only in the last several thousand years has intelligent and sentient life, namely humans, made its mark on the globe. And only in the past one hundred years have we seriously begun observing and exploring the cosmos, and also sending out signals of our own. Humanity won't be around forever; an extinction event, either natural or man-made, could cut short

Have we already found life?

There have been several instances where controversial evidence suggested that we may have already found life elsewhere in the universe

Allan Hills 84001

In Antarctica on 27 December 1984, a team of American scientists found a meteorite named Allan Hills 84001 (ALH 84001) that shot to fame 12 years later when it was announced that it might contain microscopic fossils of Martian bacteria. However, no conclusive evidence could prove whether this was so.



The Viking probes

In 1976, NASA landed two probes on Mars, Viking 1 and 2, which had instruments to perform biological experiments on the surface. Controversy surrounded the results; early indications suggested they'd found evidence of organic compounds, but some claimed that the nature of the experiment, which heated soil samples, would have destroyed organics, suggesting the results were erroneous.

Translating an alien language

Dr John Elliott

BIO

Dr John Elliott
Dr Elliott is a Reader in Intelligence Engineering at Leeds Metropolitan University in the UK. He has been involved with SETI since 1999, and his research includes the post detection decipherment of an extraterrestrial signal.

What work do you do for SETI?
My contributions in the academic side are in being able to understand the structures in the signal if we receive one. There's been at least one occasion where I've looked at a signal, just to see if there's any structure in there. So if they pick something up, I'll be looking at the content to see if there's anything in there that denotes intelligence, any sort of linguistic phenomena or imagery or anything with structure that's actually conveying information.

How confident are you that you could decipher the message?
It obviously all depends on the amount of content you've got. If it was just a short burst, like the Wow! signal, then you're up against it. But if it was someone on the other end broadcasting an encyclopedia, then you've got a great chance of deciphering it. And if there's a crib [key] attached to it then you've got some way to unlock it or decipher it. If it's something very simple but with enough information then you could start to pick it apart and be able to have a good guess at what they are saying like "hello", "we are here", this sort of thing.

Would you respond to their message?
The flip side of all this is message construction. Because of the nature of the deciphering side I'm sort of one of the main people that deals with the message construction because one is relevant to the other. Constructing a message is a big debate for SETI, it splits us down the centre. Should we send a message back? Many of us, me included, are in the camp that, yes, for God's sake, they're going to be huge distances away from us, let's just try to communicate!

What would we say to them?
The obvious thing is to copy what they've sent back to them with something of our own included. There are some people that send messages [without consent] anyway. People are sending messages purposefully out from Earth, and that's an issue. While we are debating whether to send a message, some people are already sending them. You'll end up in the hands of amateurs there if you don't watch it.

Will we ever find a signal?
Yes. There's a huge universe, at least ten to the power of 21 stars out there, and there's at least that number of planets. We've only just started searching the sky. Our ability to listen to the universe is exponentially growing. There are so many planets out there in habitable regions that, just through the power of measuring probability, life has got to be out there. I can't think of a sensible argument that would say it isn't. I wouldn't mind putting money on it, although I might not be around by the time they find it! But I think they will.

"I'll be looking at the content to see if there's anything in there that denotes intelligence"

Get involved with SETI

If you're interested in becoming an alien hunter, then there's never been a better time to get involved with the SETI Institute. Head over to the website at www.seti.org to find out more.

You can also sign up for SETI@Home, a piece of software that runs in the background on your computer and makes use of processing power that is otherwise unused.

our ambitions to continue exploring. That would mean that an intelligent civilisation has only a brief period to make a mark in the lifetime of their planet. If we're going to find one, we're going to need to continue our extensive search, as it may be that every habitable planet has only a comparatively brief window in which intelligent life thrives.

However, searching for intelligent extraterrestrial life isn't the only hunt currently on the go. As mentioned earlier, our robotic exploration of the Solar System is looking at the possibility of microbial life residing on the surface of Mars, or perhaps one of the potentially habitable moons such as Europa, Ganymede or Titan. From landers to orbiters to probes, we've barely scratched the surface of the secrets some of the other destinations in our Solar System might be hiding.

In the mid-Seventies, NASA conducted the first astrobiology experiment outside of Earth, sending its Viking 1 and 2 landers to Mars to dig into the soil and look for signs of past or present life on the Red Planet. The results proved to be inconclusive but they sparked a hunger to learn more; right now, the Curiosity rover is making its way across the Martian surface to answer the very same question. And even here on Earth, research is proving useful. We've found life in the deepest, darkest and coldest places, whether it's at the bottom of a frozen lake or in highly acidic environments. Research like this could help us to one day look for life on frozen worlds like Europa or liquid-bearing places like Titan. In this regard, astrobiologists are hopeful of one day discovering microbial life.

Therefore, in our continued hunt to prove that Earth is just one world where life has made a mark in the universe, it will be down to the work of various people around the globe to make the vital discoveries that could indicate the presence of intelligent or basic life elsewhere. Whether it's experts at NASA working on a high-profile, next-generation planet-hunting machine such as the James Webb Space Telescope, or it's the valiant workers who are looking for signals outside of our Solar System at SETI, or even the astrobiologists searching for bacteria on another world, these dedicated people will continue to work towards finding alien life. They are convinced we are not alone in this universe and they aim to prove it, one way or another.

5 amazing facts about Rockets

The first rocket landed in a cabbage patch

The first-ever liquid-fuelled rocket was launched by American Robert Goddard on 16 March 1926, although the Chinese used solid-fuel rockets a thousand years prior. Goddard's rocket climbed 12.5m (41ft) before crashing in a cabbage patch. However, he was widely derided for suggesting a rocket could one day take humans to the Moon.

The Saturn V was heavier than 400 elephants

Coming in at a massive 2.8 million kg (6.2 million lb), the Saturn V is the most powerful rocket to have ever been launched. It was as tall as a 36-storey building and could take the equivalent of ten school buses into Earth orbit, while the amount of fuel it used could have driven a car around the world 800 times.

Paint designs keep track of rockets

Many rockets use different paint styles so ground controllers can track their motion, roll and orientation. The iconic Saturn V used chequered paint for this purpose, as did the early Redstone and Titan rockets. Modern rockets use the External Vehicle Markings (EVM) Document, which outlines a function for each paint marking.

The fastest rocket ever approached Mach 50

The quickest rocket to ever be launched was a five-booster configuration Atlas V on 19 January 2006. It carried the New Horizons spacecraft, which is currently on its way to Pluto, and reached over 58,000km/h (36,000mph). At this speed it got to the Moon's orbit in just nine hours, compared to the three-day journey time for Apollo astronauts.

Russia has launched the most rockets

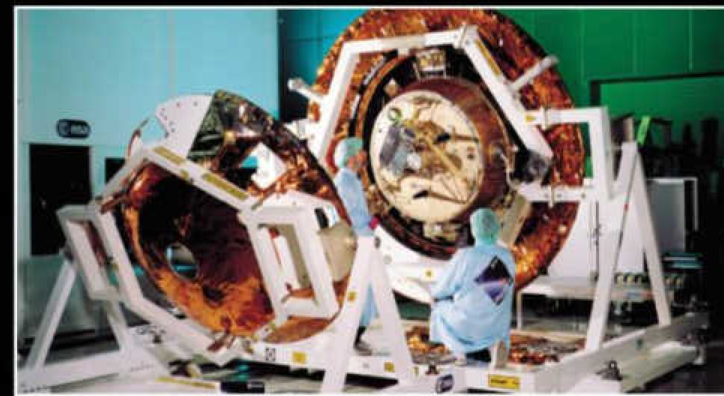
As of December 2011, 50.5% of all spacecraft launches (3,595) were carried out by Russia. Of the 7,120 spacecraft launched, the USA is responsible for 1,857 (26.1%), while Europe's count is at 338 (4.8%). Since the dawn of the space age in 1957 the busiest year for rockets so far was 1965, when 180 spacecraft were launched.

Landing on Titan

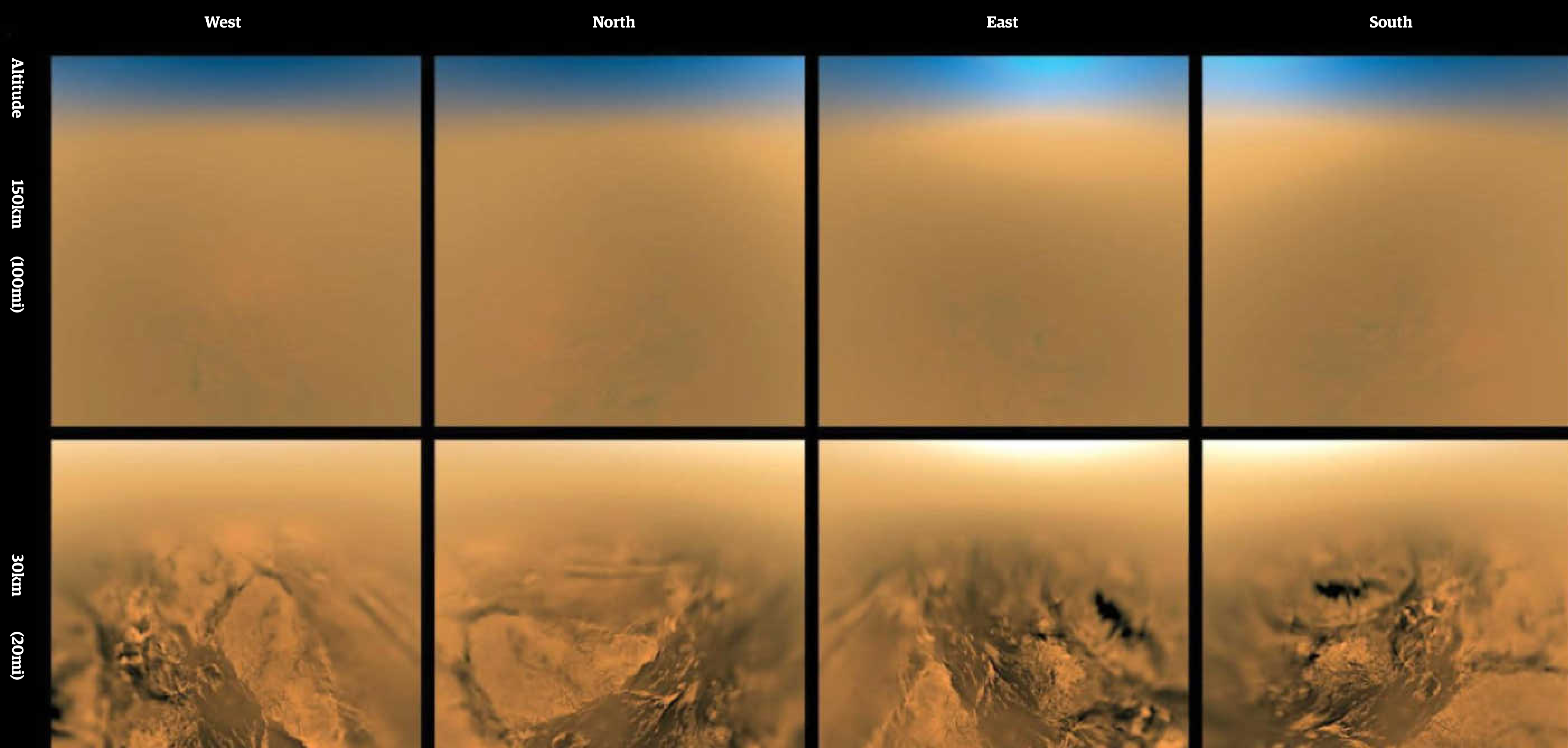
Celebrating the eleventh anniversary of the Huygens probe's descent to the surface of Saturn's giant moon

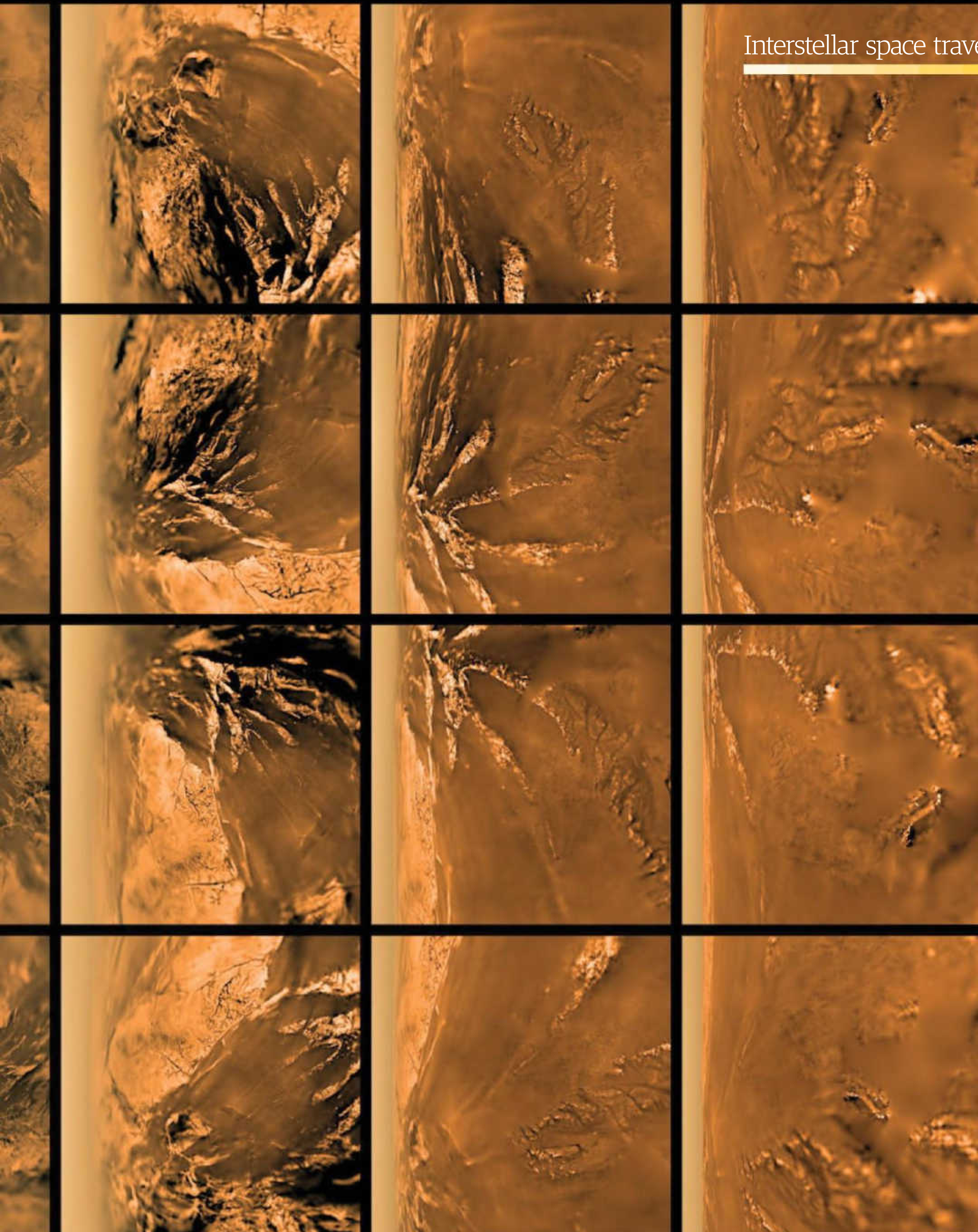
Over a decade ago, on 14 January 2005, the European Space Agency's Huygens probe separated from NASA's Cassini orbiter around Saturn, and began its descent onto Titan. Although it only transmitted data from the surface for 72 minutes before losing contact with Cassini, and a problem with its programming meaning half the images and data it received was lost, Huygens was still considered a huge success. It's the only successful soft landing on a world in the outer Solar System, the images returned are the first taken from a surface in the outer Solar System, and Huygens remains the most distant landing of any man-made spacecraft today.

The images taken here showed, for the first time, what was beneath the impenetrable yellow haze of Titan's dense nitrogen atmosphere: a relatively smooth surface with a few mountains and ice volcanoes, plus lakes of liquid hydrocarbons in the moon's chilly average temperature of around -180 degrees Celsius (-292 degrees Fahrenheit).



The Huygens descent module is seen here being tended to by two ESA scientists. The huge copper disc at the front is the vital front shield, which protected Huygens from the blistering heat of atmospheric entry





8km (5mi)

1.5km (1mi)

0.3km (0.2mi)


Scale
93m
Statue of Liberty
111m
SLS block 2 configuration

The world's BIGGEST ROCKET

A marvel of modern space engineering, the Space Launch System is set to take humanity further into space than ever before

Ever since the launch of the Juno I - the rocket which sent the United States' first satellite, Explorer 1, into orbit in 1958 - American astronomers, engineers and astronauts have been looking far beyond our atmosphere and further than our own lone lunar satellite – the eyes of the space engineering industry have been firmly set not just on our Moon, but toward Mars and distant asteroids.

However, in order to travel those incredible distances, you need an equally incredible feat of engineering to take you there - a launch vehicle with the thrust and capacity to take humanity distances that only probes and unmanned spacecraft have traversed before. Distances that are normally covered in slow, steady states of hibernation. The answer to that dream lies in a $35-billion (£23-billion) planned mission, powered by the most powerful rocket ever created – the Space Launch System.

So how did it all come together? The origin of the SLS can be traced back to the NASA Authorization Act of 2010, which called for the development of a brand new heavy-lift rocket. The Saturn V, the last heavy-lift rocket used by NASA, was taken out of service in 1973 and since then nothing in the American space agencies' fleet could match its incredible power and capacity.

"The original concept was a capability which the US and its international partners will rely on to enable exploration beyond low-Earth orbit for the better part of the 21st century," reveals Jay Onken, deputy chief engineer of the SLS. "The NASA team completed a series of studies as part of a Requirements Analysis Cycle (RAC), in parallel with 13 complementary studies conducted by private industry, under Broad Agency Announcement (BAA) contracts. The results of these efforts converged on a Mission Concept Review (MCR) in the spring of 2011." These activities helped to determine the feasibility of meeting top-level missions with the launch vehicle set ups available in the US at the time. The NASA planning team used these different trade studies to evaluate alternative options to meet the NASA's 'Human Exploration' goals. "These studies, which included independent reviews of the projected development cost and development schedule, resulted in a recommendation that extracted the 'best' elements from possible solutions," adds Onken.

"NASA administrator, Charlie Bolden selected the space vehicle's design after reviewing the various of architectures and alternatives." And with that, the Space Launch System (SLS) was born.

"It will offer game-changing benefits, making manned space exploration missions possible" **Jay Onken, SLS deputy chief engineer**

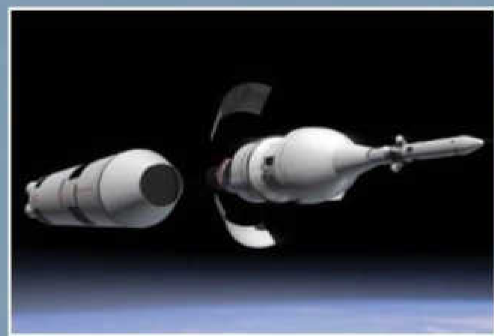
The SLS incorporates components from the Space Shuttle program

The SLS is the first heavy-lift operation to be designed and constructed by NASA since the Saturn V in the Sixties and Seventies

Block 1, used for EM-1 and EM-2, will have a lift capacity of around 70 metric tons

Rocket of the future

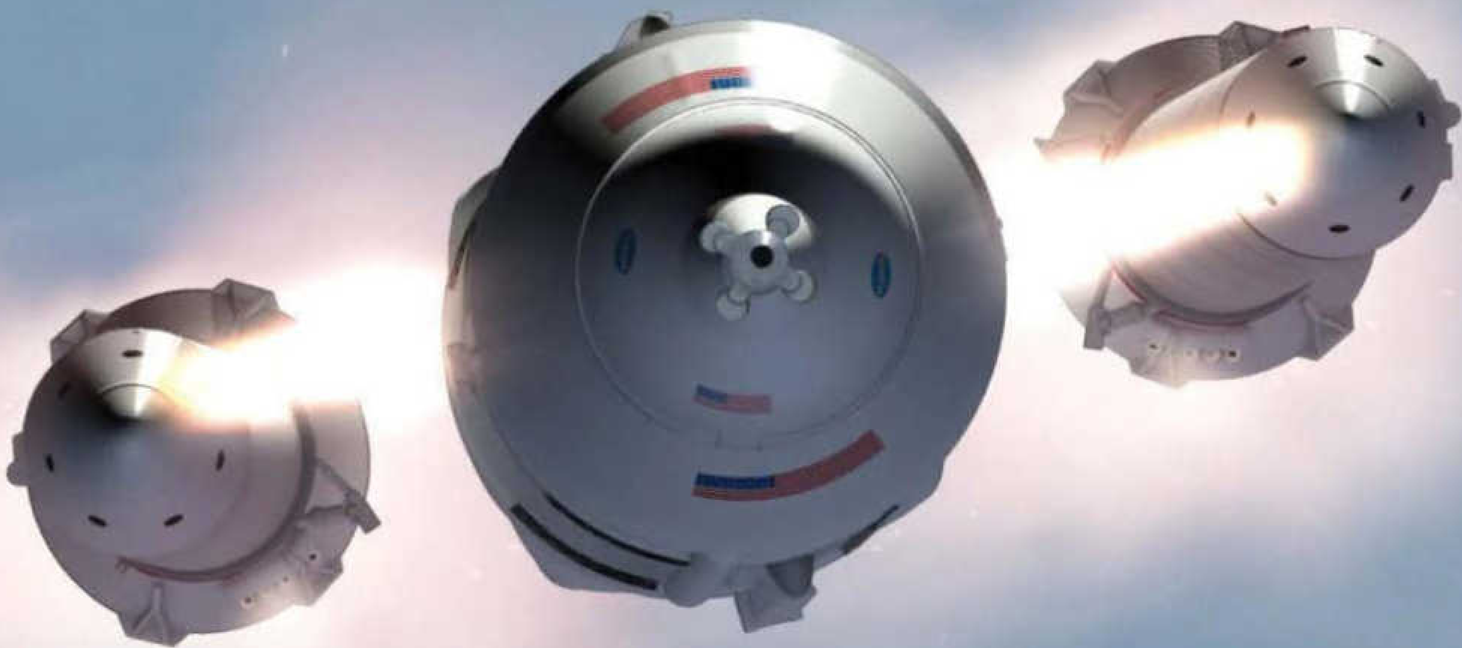
From its three planned missions to some of the biggest of its proposed journeys, these are the voyages of the SLS



Exploration Mission-1
Set to launch in November 2018, the first mission will take an unmanned Orion capsule around the Moon and back to test the in-space capabilities of the SLS.

Exploration Mission-2
The second mission, EM-2, is planned to launch sometime between 2021 and 2023, carrying a crew of four people on a retrograde lunar orbit.

Exploration Mission-3
EM-3, the third and final mission on the officially planned list, will launch in 2026, sending another four-man crew to a robotically-captured asteroid.



Uranus orbiter and probe
Airplane multinational Boeing has proposed that the SLS be used as a launch vehicle for a probe bound for Uranus.

Strategic timeframe design reference missions to the Moon
Alongside a series of lunar probes that will hopefully lead to a lunar base, NASA will dual-launch crafts to geostationary orbits.

ISS back-up crew delivery
Should the other vehicles that normally ferry astronauts to the International Space Station fail or become unavailable, the SLS will temporarily take on their role.

Five NEA missions
Proposals for five separate Near-Earth Asteroid (NEA) missions that will aim to visit, study and potentially capture asteroids passing close by to Earth.

The question is, why did it take over four decades for NASA to finally design and construct a heavy-lift system to replace the Saturn V program that ran during the 1960s and 1970s? The answer is simpler than you might imagine. After the Cold War driven Space Race to the Moon, NASA realised it was attempting to reach out into the stars without truly understanding the environment in which they were working. "After the Saturn V was retired in the 1970s, President Richard Nixon directed NASA to focus on building the Space Shuttle for more routine access to low-Earth orbit," explains Onken, in regards to the phase that would eventually lead NASA back to heavy-lift operations.

"America's first Space Station, Skylab, was launched, and Americans broke world records for time spent in space on those missions," he adds. "NASA learned a lot about how people and materials were affected by microgravity and the space environment, and before longer space missions to the Moon and Mars could be planned, these questions needed to be answered. The Space Shuttle and the International Space Station, which has been occupied by humans continuously since 2 November 2000, allowed NASA to learn a great deal about living and working in space."

The now defunct Space Shuttle program would also play a major role in the future of the SLS, mainly due to the inclusion of the Space Shuttle's own booster rockets in the new mega vehicle's design. So what was the reasoning behind the use of components first used at the start of the 1980s? It all comes down to keeping the elements that proved the most successful and durable from past endeavours.

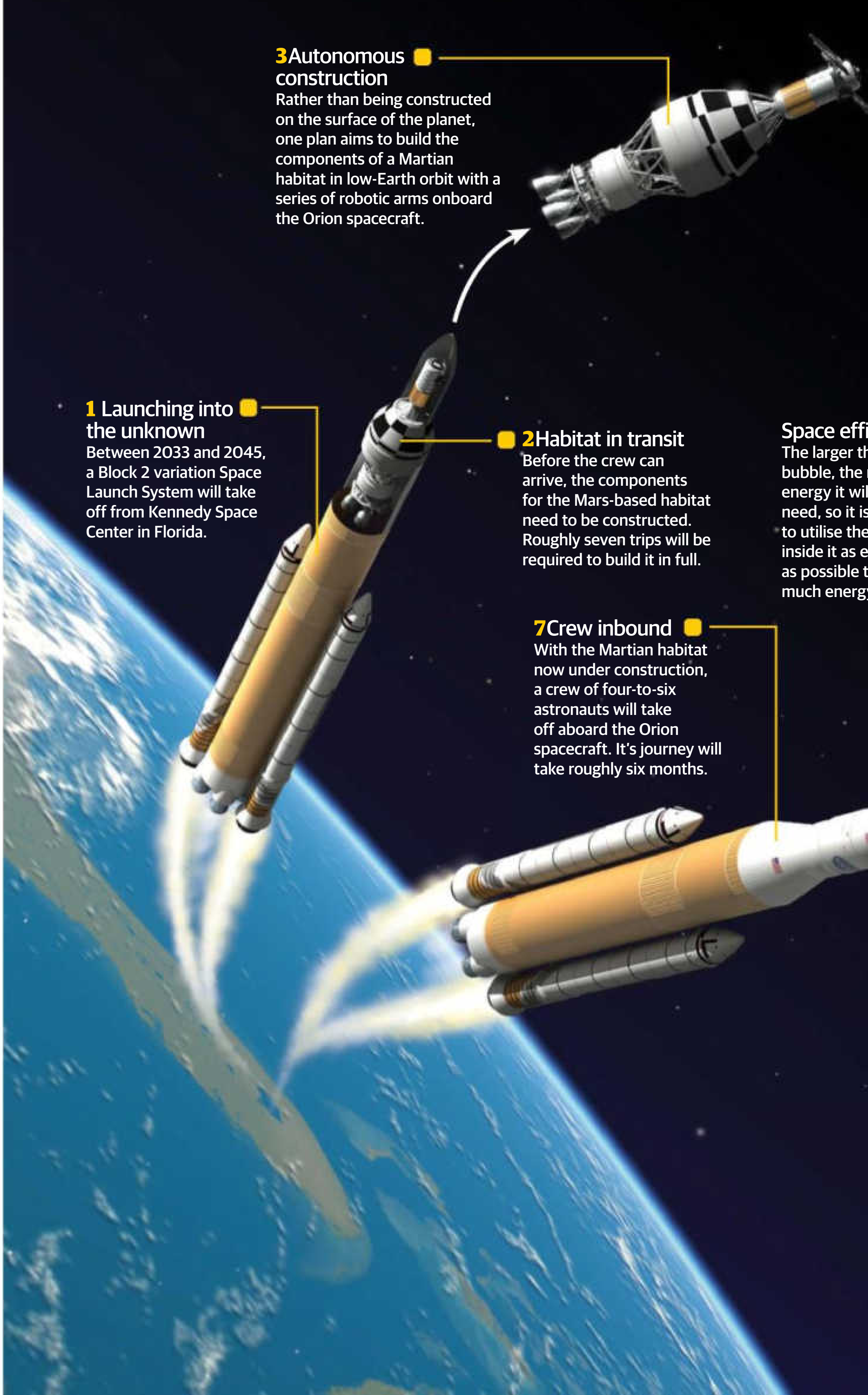
"The SLS incorporates components from the Space Shuttle program because of the reliability of these systems and to provide an affordable means to start the program," adds Onken. "For example, developing a new engine tends to be the most expensive part of any program - we are starting with a very proven, reliable engine and therefore do not have the added expense of designing, developing, testing and manufacturing the engine."

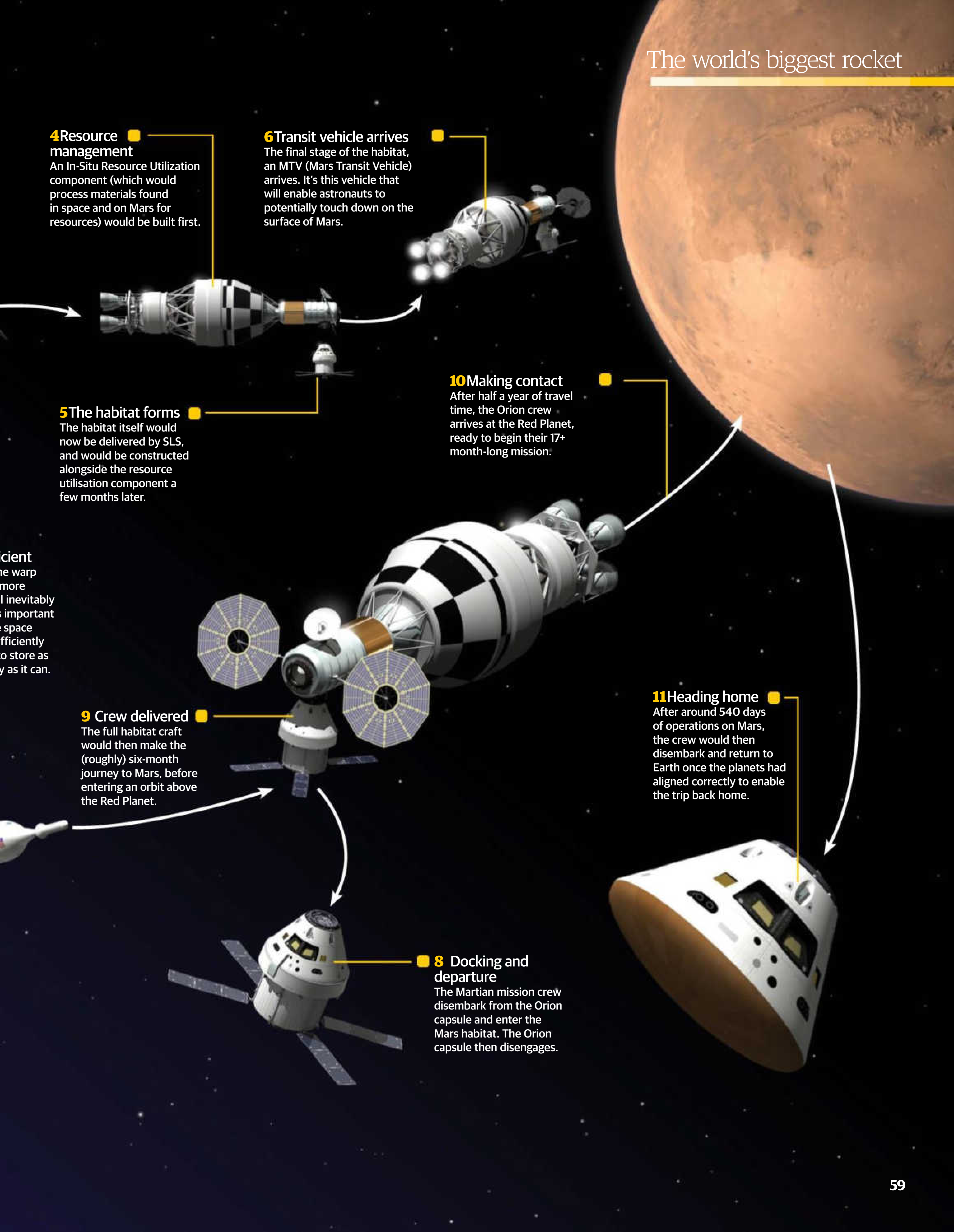
The Space Launch System aims to take all those existing technologies and create the most powerful rocket ever constructed. It's more than double the size of any space vehicle currently in operation and will offer 15 per cent more thrust than the decades old Saturn V. Unlike any other rocket in NASA's history, the SLS will be split into three separate designs, each one tailored for specific missions at distinct distances from the Earth. The first, Block 1, will have a lift capacity of around 70 metric tons and will be used for Exploration Mission-1 (EM-1) and Exploration Mission-2 (EM-2).

Exploration Mission-1, set for launch in November 2018, will carry the unmanned Orion spacecraft, as well as 13 secondary science payloads. These payloads include; the Lunar Flashlight, a spacecraft with a solar sail that will determine the presence (or indeed the absence) of water ice at the lunar south pole; the BioSentinel, an astrobiology device that will use something as commonplace as yeast to study the effects of deep space radiation on living organisms; and the Near-Earth Asteroid Scout, another solar sail powered craft, this time focused on studying spacefaring bodies passing near our planet's

Mission to Mars

Perhaps the most ambitious of the proposed space missions, the SLS plans to carry a crew of four-to-six astronauts to a habitat on the Red Planet





4 Resource management
An In-Situ Resource Utilization component (which would process materials found in space and on Mars for resources) would be built first.

6 Transit vehicle arrives
The final stage of the habitat, an MTV (Mars Transit Vehicle) arrives. It's this vehicle that will enable astronauts to potentially touch down on the surface of Mars.

5 The habitat forms
The habitat itself would now be delivered by SLS, and would be constructed alongside the resource utilisation component a few months later.

10 Making contact
After half a year of travel time, the Orion crew arrives at the Red Planet, ready to begin their 17+ month-long mission.

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9 Crew delivered
The full habitat craft would then make the (roughly) six-month journey to Mars, before entering an orbit above the Red Planet.

11 Heading home
After around 540 days of operations on Mars, the crew would then disembark and return to Earth once the planets had aligned correctly to enable the trip back home.

8 Docking and departure
The Martian mission crew disembark from the Orion capsule and enter the Mars habitat. The Orion capsule then disengages.

atmosphere. All of them will operate in different areas, all of them powered by the thrust of the SLS.

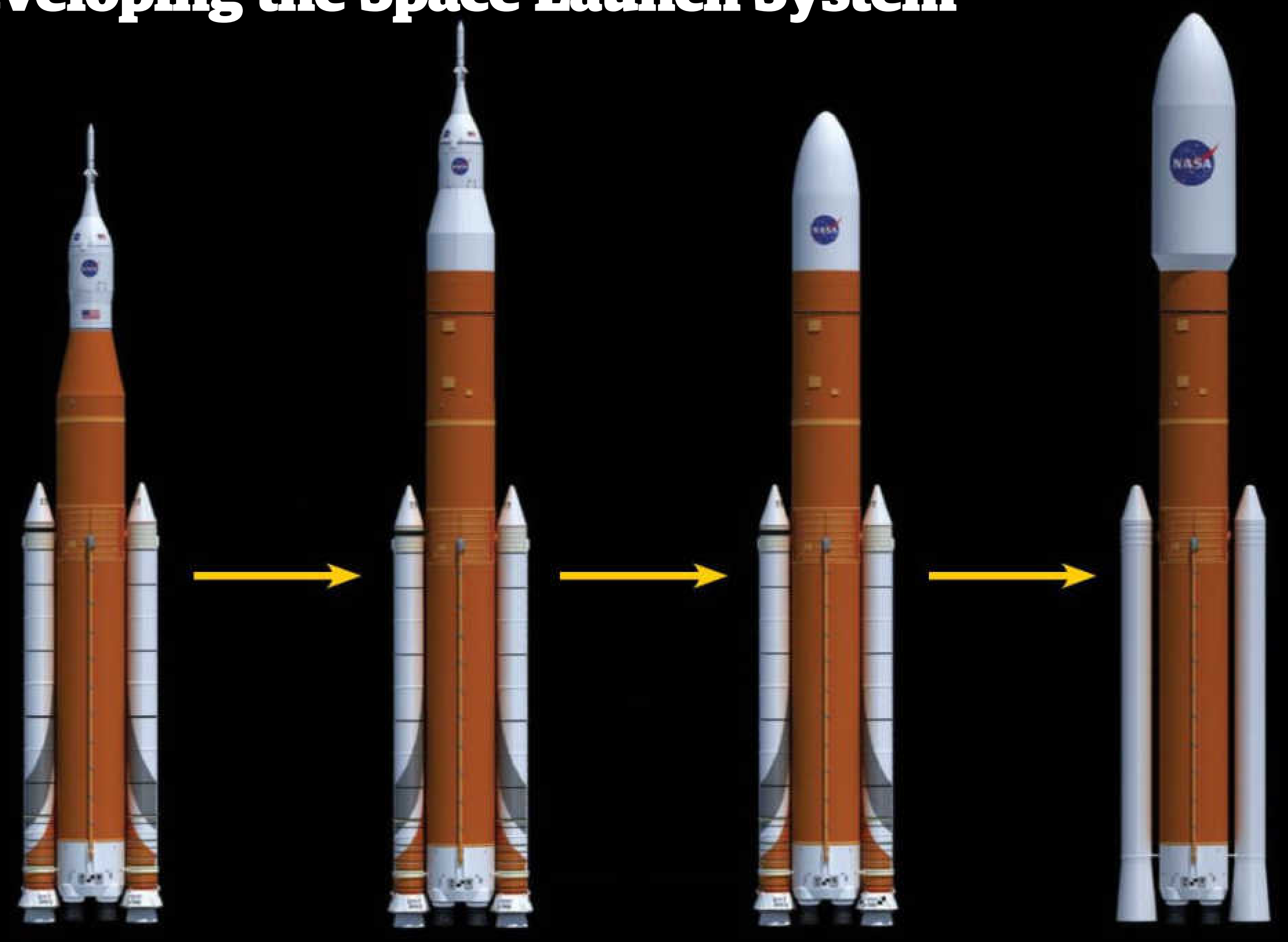
That first design will be powered by two five-segment Solid Rocket Boosters, four RS-25D engines (previously used as part of the Space Shuttle program), and an Interim Cryogenic Propulsion Stage, which is based on the payload motor used by the Delta IV evolved expendable launch vehicle. On lift off, the Block 1 variation will produce nearly 4 million kilograms (8.8 million pounds) of thrust, which is equivalent to an incredible 31 times the thrust of a Boeing 747 jet. The Block 1 SLS also weighs a staggering 2.6 million kilograms (5.75 million pounds), the equivalent of eight fully-loaded 747s. It will also be one of the tallest rockets ever constructed at 98 metres (322 feet) tall – essentially a skyscraper that will blast into space.

"We are starting with proven high-performance RS-25 core stage engines from the Space Shuttle inventory," says Onken on some of the new innovations being used to make the Space Launch System a reality. "Building on 30 years of experience and engine success, which reduces both risk and cost, we now have 16 RS-25 engines – enough for the first four flights – currently in inventory at the Stennis Space Center. Testing on a RS-25 development engine finished in August 2015 and work is underway to begin testing on flight RS-25 engines." Other enhancements are currently in progress for the engines. For example, NASA is working with Aerojet Rocketdyne on plans to restart production of a more affordable variant of the RS-25 engine that is tested and certified for flight at a higher thrust level. This future engine will implement a much more simplified design and new manufacturing and inspection technologies and processes. These will reduce handling and support labour, hardware defects and production time – in other words, it's a design that works at a price that's far more affordable.

The second variation of the Space Launch System, Block 1B, will provide even more power with a lift capacity of around 105 metric tons. It will be even bigger than the Block 1 iteration, more

"This giant rocket's incredible thrust will be about 31 times that of a Boeing 747 jet engine"

Developing the Space Launch System



SLS Block 1
November 2018
The SLS is designed to make passes around the Moon and return to Earth. It will utilise solid rocket boosters, an Interim Cryogenic Propulsion Stage (all it needs to make this relatively short test flight) and the Orion spacecraft.

SLS Block 1B Crew
2021-2023
If the SLS Block 1 tests with an unmanned crew are successful, the Block 1B model will then be launched. It will conduct exactly the same mission as the Block 1 rocket but this time with a crew of four astronauts.

SLS Block 1B Cargo
2030
The next stage of the Space Launch System's evolution is using the Block 1B to carry heavier payloads to low-Earth orbits and beyond, such as the components for the proposed Forward Work Mars Landing mission.

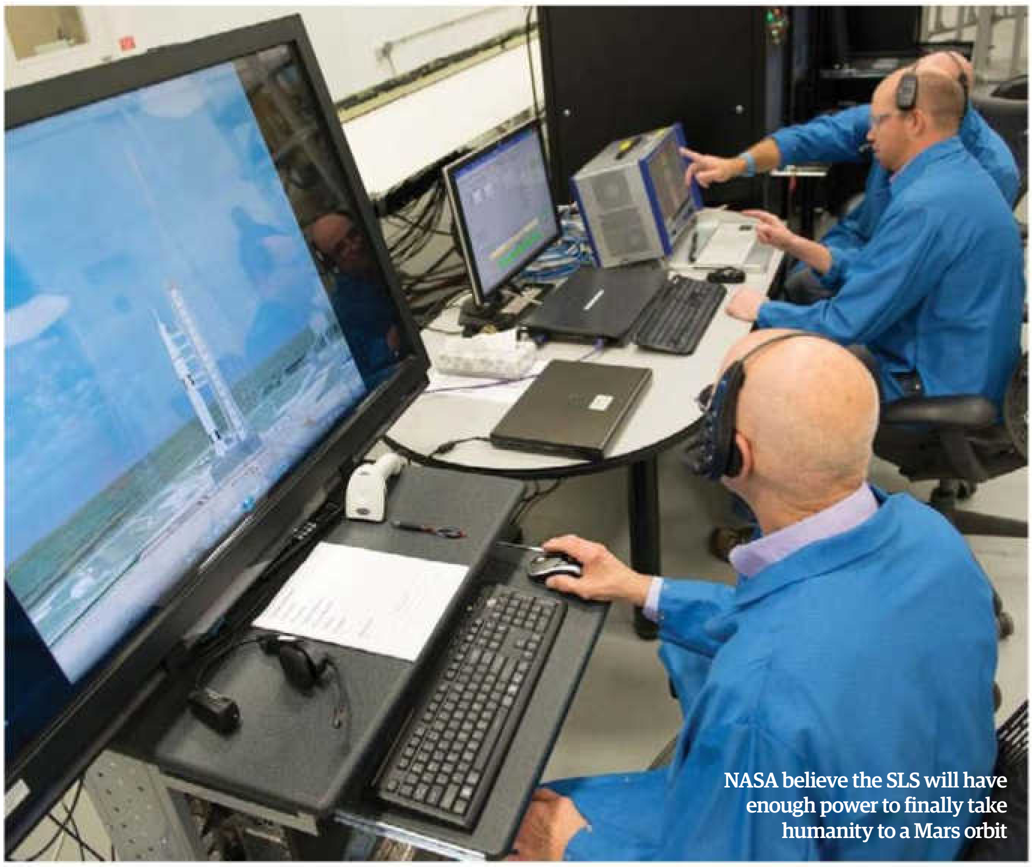
SLS Block 2 Cargo
2033-2045
The ultimate goal is to launch the final stage of the evolved SLS – larger and more powerful than its previous incarnations, the Block 2 would transfer crews and large cargo payloads to Mars and nearby passing asteroids.

or less matching the height of its predecessor the Saturn V at a huge 110.9 metres (364 foot) tall. That additional height and weight all comes from an extra component that will distinguish this phase from others in the SLS design: the Exploration Upper Stage. Forming a key part of Exploration Mission-2, the Exploration Upper Stage will replace the Interim Cryogenic Propulsion Stage and serve as the basis for more ambitious crew and science missions to the proving ground of space, near the Moon and beyond, where NASA will test systems for Mars missions.

The third and, currently, final stage of the Space Launch System will be Block 2 and, like Block 1B, it will be designed to take both manned and unmanned cargo further than ever before. It's this variation of the SLS that will aim to take humans to the Moon, to asteroids for the first time, and even out to Mars in the not too distant future. Every element of the Block 2 will break records in space engineering and space-based flight. At 111.2 metres (365 foot) tall it reaches higher than a 30-story building, while its weight of 2.9 million kilograms (6.5 million pounds) weight is as heavy as ten fully-loaded 747 jets! The SLS will be NASA's first exploration-class vehicle since the Saturn V took American astronauts to the Moon more than 40 years ago, and will expand our reach in the Solar System, launching crews of up to four astronauts aboard the new Orion spacecraft to explore multiple, deep-space destinations. Outside of its three main Exploration Missions, the SLS stands as a platform for humanity's endeavours beyond the low-Earth orbits that have categorised spaceflight for the last three decades.

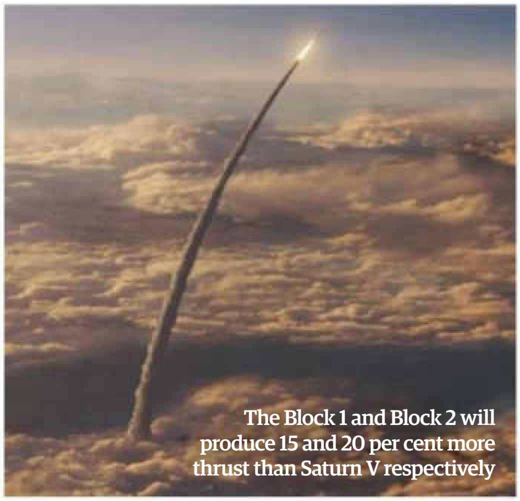
"In addition to making human exploration missions possible, the SLS offers game-changing benefits for potential robotic science missions and other payloads," adds Onken. "Its lift capability enables the launch of larger payloads than any other rocket; its high performance decreases the time it takes for robotic spacecraft to travel through the Solar System, and by extension, cost and risk; and its ability to carry larger payloads provides volume to fly unique science missions that are otherwise too large to fly on commercial rockets."

Perhaps most important of all, the SLS will be the vehicle with the power to finally take humanity to a Mars orbit. The Block 2 variation will, if the planned Forward Work Mars Landing program goes ahead, be the rocket that finally reaches that Martian milestone. The proposal aims to take a crew of four-to-six astronauts 54.6 million kilometres (33.9 million miles) away to the Red Planet (a journey of roughly six months) aboard a pre-constructed orbital habitat. Of course, such a ground-breaking construct wouldn't arrive with the crew – in fact it will take a total of seven Block 2 rockets. Each one will be powered by nuclear propulsion modules, and will be constructed in-orbit before being made habitable. The crew will spend roughly 540 days onboard the habitat while the planets align again, thus enabling them to make the six-month return journey home. It's an incredible feat and one that's still decades away – the project team behind the proposal hopes to use the Space Launch System to blast off for Mars between 2033 and 2045 – but it's still just one more landmark clinging to the fuselage of the world's most ambitious space rocket ever to launch.


NASA believe the SLS will have enough power to finally take humanity to a Mars orbit

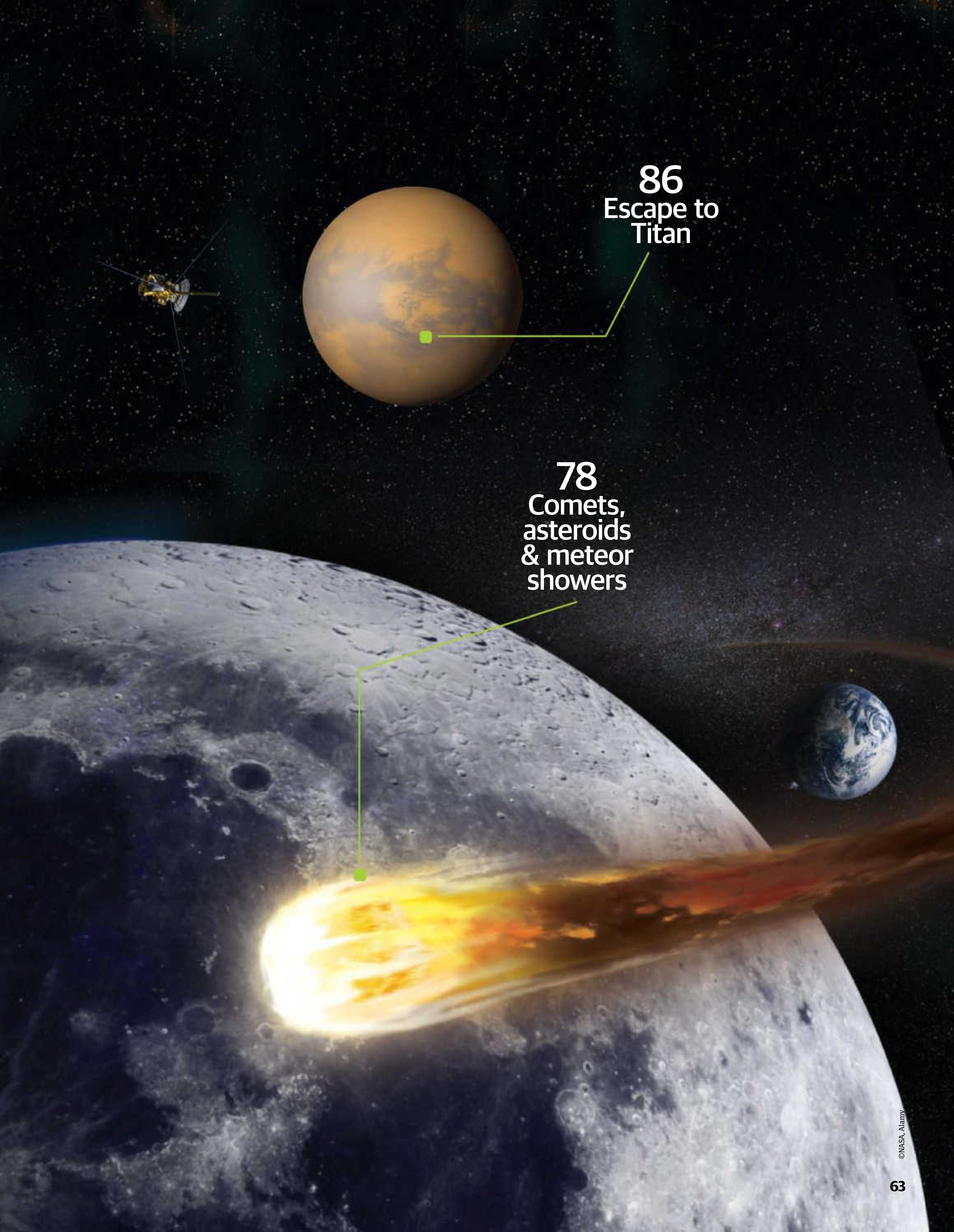

The SLS' rocket boosters (shown here during a test) are the most powerful ever built

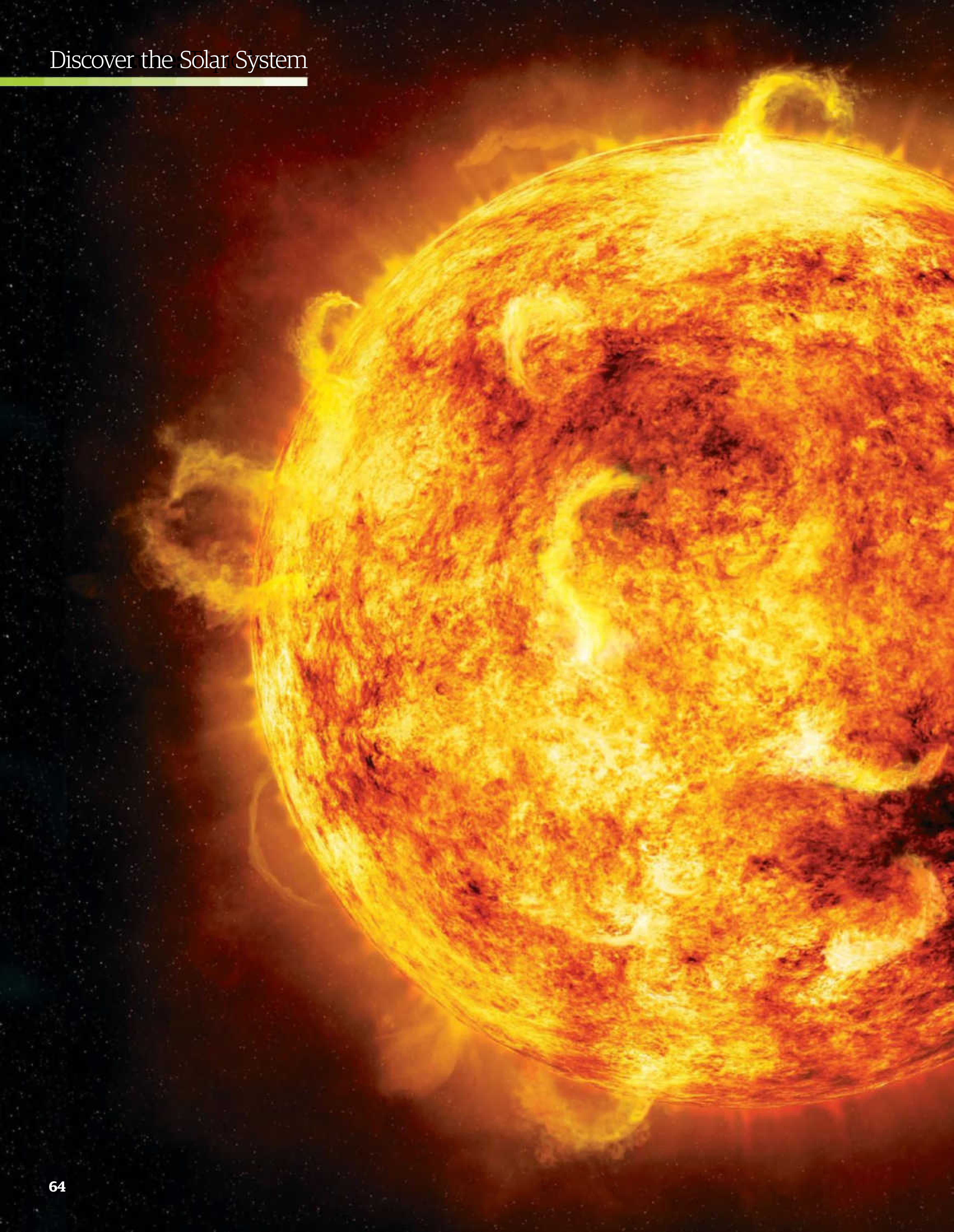

The Block 2 configuration will be over 30-stories tall at 111m (365ft)


The Block 1 and Block 2 will produce 15 and 20 per cent more thrust than Saturn V respectively

Discover the Solar System

Exploring the wonders of our Solar System


86
Escape to Titan
78
Comets, asteroids & meteor showers
©NASA, Alamy



All About... THE SUN

The vast nuclear furnace that we know as the Sun is responsible for dictating the seasons, climate and characteristics of every planet in the Solar System. Here, we take an in-depth look at this source of power that has astounded humanity since the dawn of existence

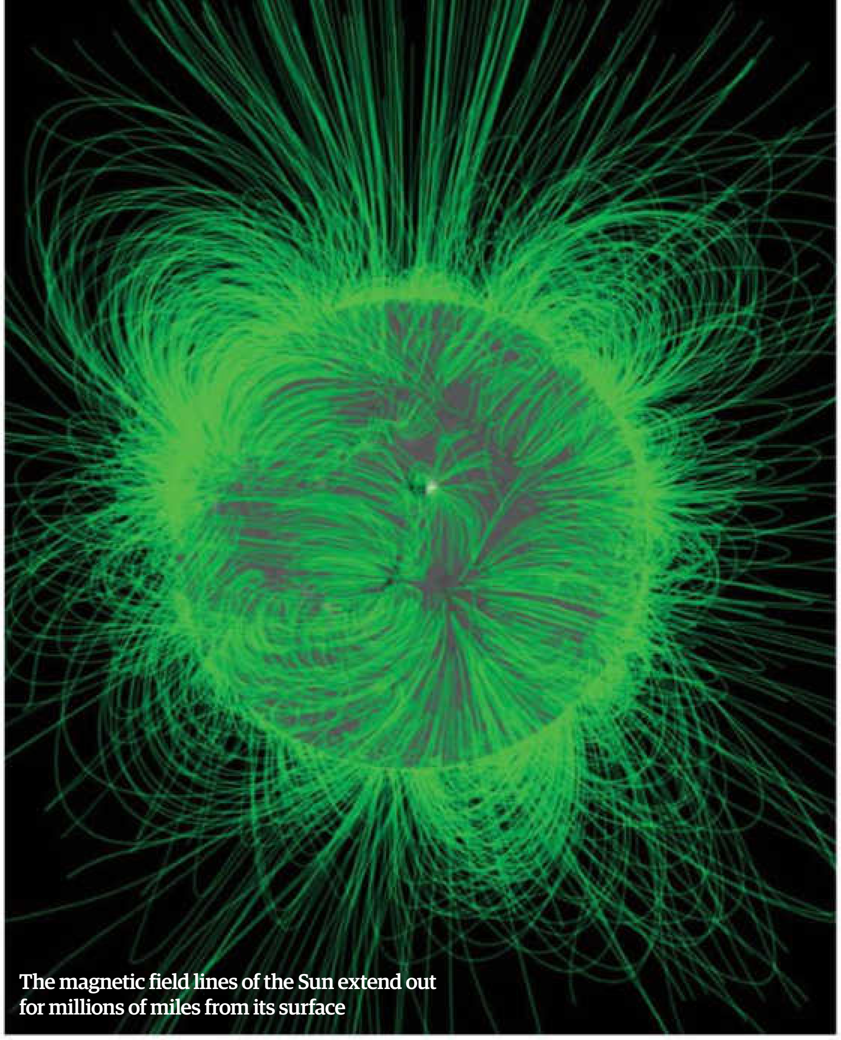
At about 150 million kilometres (93 million miles) from Earth lies a giant incandescent ball of gas weighing in at almost 2,000 trillion trillion kilograms and emitting power equivalent to 1 million times the annual power consumption of the United States in a single second. Since the dawn of Earth 4.6 billion years ago it has been the one ever-present object in the sky, basking our world and those around us in energy and light and providing the means through which environments, and ultimately life, can flourish. We see it every day and rely on its energy to keep our planet ticking, but what exactly is this giant nuclear reactor at the centre of the Solar System that we call the Sun?

Over 5 billion years ago a vast cloud of dust and gas was located where our Solar System is now. Inside this nebula something huge was happening; gravity was pulling together the debris, likely the remnants of another star going supernova, into one central mass. As the various metals and elements were brought together they began to fuse into an object at the heart of this nebula. This dense clump of matter, called a protostar, grew and grew in size until it reached a critical temperature due to friction, about 1 million degrees Celsius (1.8 million degrees Fahrenheit). At this point nuclear fusion kicked in and our Sun was born.

At the heart of the Sun, hydrogen atoms fused together to produce helium, releasing photons of light in the process that extended throughout the Solar System. Eventually the hydrogen and helium atoms began to fuse and form heavier elements such as carbon and oxygen, which in turn formed key components of the Solar System, including humans. To us, it's the most important object in the sky. An observer watching from afar, however, would see no discerning qualities of our star that would make it stand out from any of the other hundreds of billions of stars in the Milky Way. In the grand scheme of things it's a fairly typical star that pales in comparison to the size of others. For instance Sirius, the brightest star in the night sky, is twice as massive as the Sun and 25 times more luminous while Arcturus, the fourth brightest object in the night sky is almost 26 times the size of our closest star.

The Sun is located at a mean distance of 150 million kilometres (93 million miles) from Earth, a distance known as one astronomical unit (1 AU). This giant nuclear furnace is composed mostly of ionised gas and drives the seasons, ocean currents, weather and climate on Earth. Over a million Earths could fit inside the Sun, which is itself held together by gravitational attraction, resulting in immense pressure and temperature at its core. In fact, the core reaches a temperature of about 15 million degrees Celsius (27 million degrees Fahrenheit), hot enough for thermonuclear fusion to take place. The intense physical process taking place in the Sun produces heat and light that radiates throughout the Solar System. It's not a quick process, though; it takes more than 170,000 years for energy from the core to radiate outwards towards the outer layers of the Sun.

Our Sun is classified as a yellow dwarf star and these stars range in mass from about 80 per cent to 100 per cent the mass of the Sun, meaning our star is at the upper end of this group. There are also three further groups into which stars are classified: Population I, II and III. Our Sun is a Population I star, which denotes that it contains more heavy elements compared to other stars (although still accounting for no more than approximately 0.1 per cent of its total mass). Population III stars are those that formed at the start of the universe, possibly just a few hundred million years after the Big Bang, and they are made from pure hydrogen and helium. Although hypothesised, no such star has ever been found, as the majority of them exploded as supernovae in the early universe and led to the formation of Population I and II stars, the latter of which are older, less luminous and colder than the former.


The magnetic field lines of the Sun extend out for millions of miles from its surface

By now you're probably thinking our Sun is insignificant, but that's anything but the case. Being our closest star, and the only one we can study with orbiting telescopes, it acts as one of the greatest laboratories available to mankind. Understanding the Sun allows us to apply our findings to research here on Earth, such as nuclear reactors, and our observations of distant stars. Over the next few pages we'll delve into the reasons why studying the Sun is so important and explore some of the amazing physics going on inside and outside this vast nuclear furnace.

> "The core reaches a temperature of about 15 million degrees Celsius, hot enough for thermonuclear fusion to take place"

The planets in relation to the Sun

All figures = million miles from Sun

Spicules
These supersonic jets of hot plasma form in the Sun's interior and rise to a height of around 5,000km (3,000 miles) above the Sun's photosphere.

Coronal mass ejections
A coronal mass ejection (CME) is a burst of plasma and magnetic fields, known as stellar wind, being thrown into space from the Sun's corona.

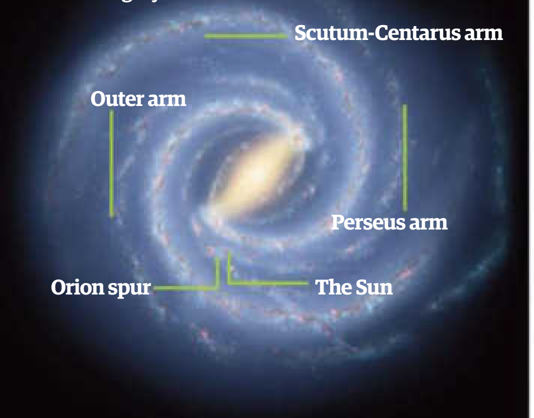
Faculae
Produced by concentrations of magnetic field lines, these bright spots appear on the Sun's chromosphere in regions where a sunspot will form.

Granulation
The Sun often appears granulated in images because of convection currents in its photosphere and chromosphere.

Prominences
These large loops of energy extend outwards from the Sun's corona. They can range over 700,000km (430,000 miles), approximately the radius of the Sun.

Sunspot
These dark spots on the surface of the Sun are caused by intense magnetic fields and are usually accompanied by a solar flare or CME.

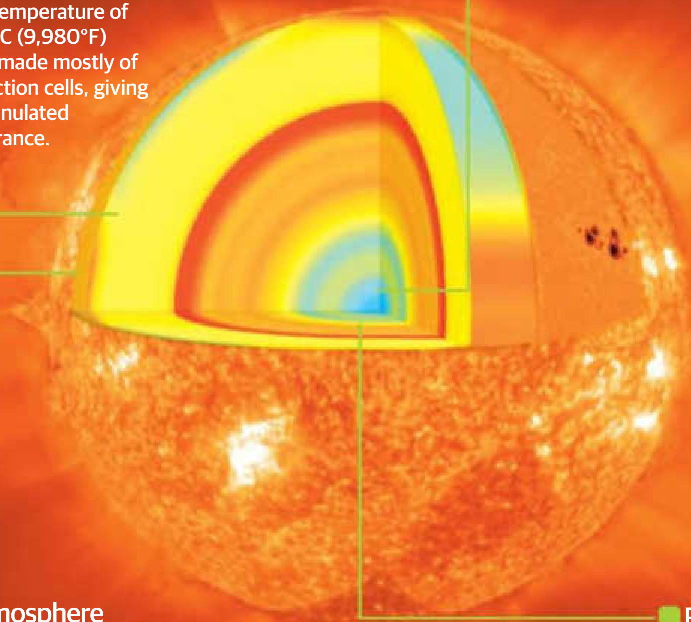
Our Solar System is located in the outer reaches of the Milky Way galaxy, which has roughly 200 billion stars



Layers of the Sun

Photosphere
The visible surface of the Sun, the photosphere, has a temperature of 5,530°C (9,980°F) and is made mostly of convection cells, giving it a granulated appearance.

Inner core
Most of the Sun's fusion power is generated in the core, which extends outwards from the centre to about a quarter of the Sun's radius.



Corona
The outer 'atmosphere' of the Sun. It is made of plasma, extends millions of kilometres outwards and has a higher temperature than the inner photosphere.

Chromosphere
This thin layer about 2,000km (1,240 miles) thick sits just above the photosphere and is the area where solar flares and sunspots are visible.

Radiative zone
This area is full of electromagnetic radiation from the core that bounces around as photon waves. It makes up about 45 per cent of the Sun.

Solar storms

Like the Earth, the Sun has an atmosphere, but the two are very different. The Sun's can be incredibly volatile with powerful magnetic activity that causes phenomena referred to as solar storms here on Earth

Solar storms are violent outbursts of activity on the Sun that interfere with the Earth's magnetic field and inundate our planet with particles. They are the result of outpourings of energy from the Sun, either in the form of a Coronal Mass Ejection (CME) or a solar flare. The former is a release of a large amount of material, mostly plasma, from the Sun while the latter is a sudden release of electromagnetic radiation commonly associated with a sunspot. While no direct connection has been found between CMEs and solar flares, both are responsible for causing solar storms on Earth. The reason why these two events occur is due to the Sun's atmosphere and its turbulent interior, with all of its components playing a part in bathing our planet in bursts of energy.

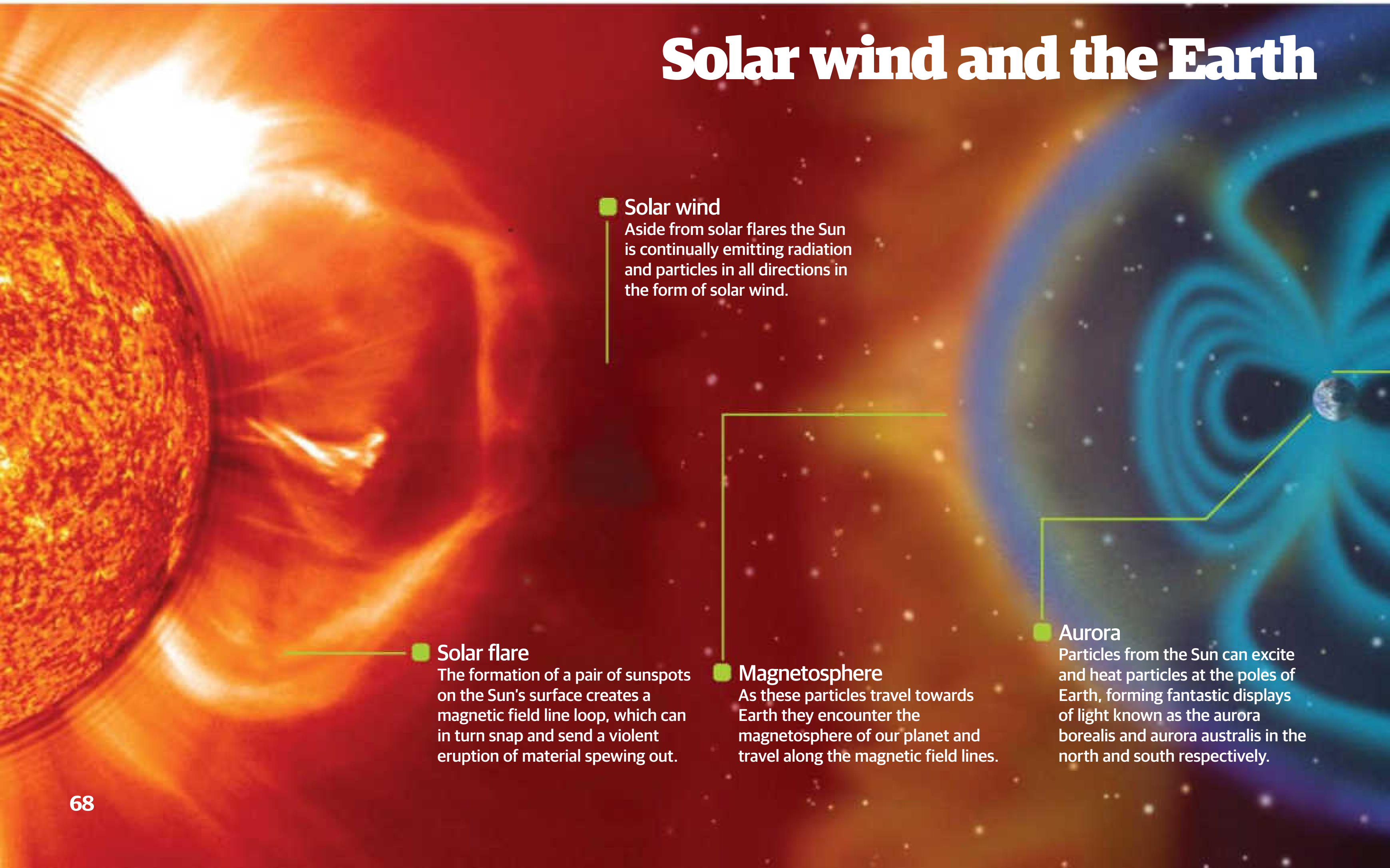
The lowest part of the atmosphere, the part directly above the Sun's radiative zone, is the photosphere. This is the visible part of the Sun that we can see, it is 300-400 kilometres (180-240 miles) thick and has a temperature of about 5,530 degrees Celsius (9,980 degrees Fahrenheit). This produces a white glow although from Earth this usually appears yellow or orange due to our own atmosphere.

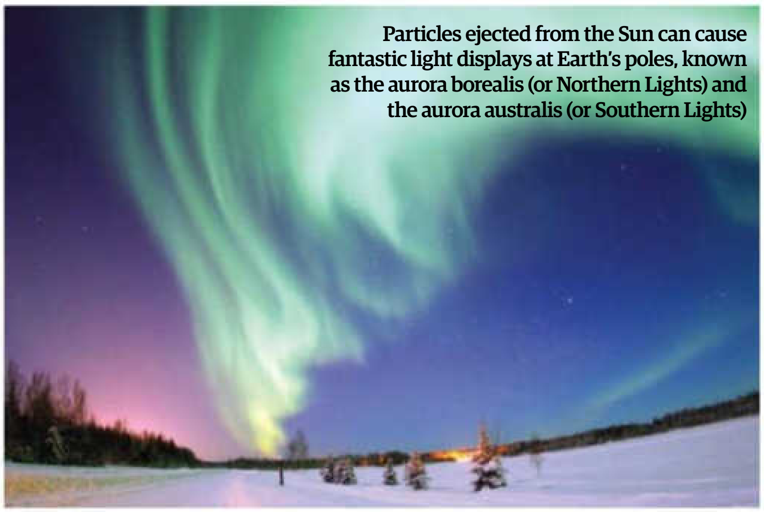
As you travel through the photosphere away from the Sun's core the temperature begins to drop and the gases become cooler, in turn emitting less light. This makes the photosphere appear darker at its outer edges and gives the Sun an apparently clearly defined outer boundary, although this is certainly not the case as the atmosphere extends outwards much further.

Once you pass through the photosphere you enter the chromosphere, which is about 2,000 kilometres (1,240 miles) thick. The temperature rises to about 9,730 degrees Celsius (17,540 degrees Fahrenheit), surpassing that of the photosphere. The reason for this is that the convection currents in the underlying photosphere heat the chromosphere above, producing shock waves that heat the surrounding gas and send it flying out of the chromosphere as tiny spikes of supersonic plasma known as spicules.

The final layer of the Sun's atmosphere is the corona. This huge

Solar wind and the Earth





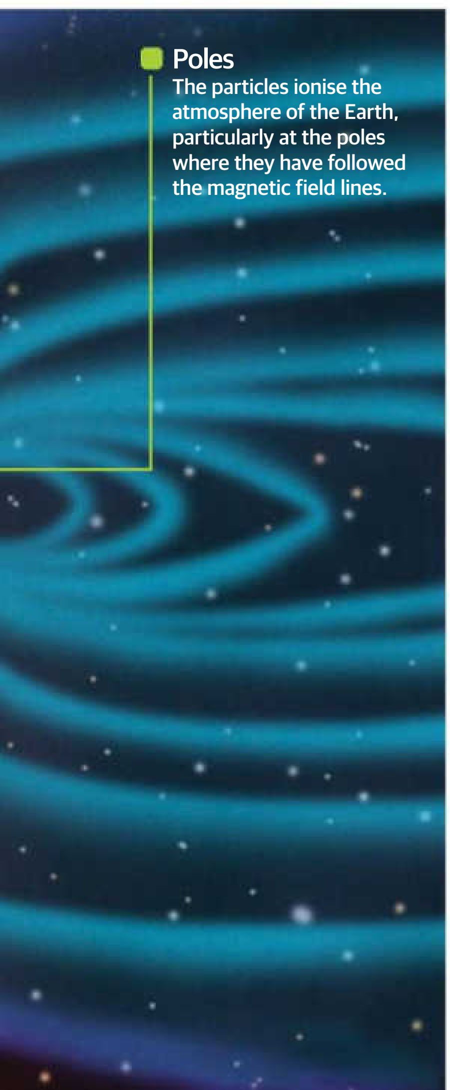
Particles ejected from the Sun can cause fantastic light displays at Earth's poles, known as the aurora borealis (or Northern Lights) and the aurora australis (or Southern Lights)

> "Once you pass through the photosphere you enter the chromosphere, which is about 2,000km thick"

expanse of material can stretch as far as several million miles outwards from the surface. Oddly, the temperature of the corona averages 2 million degrees Celsius (3.6 million degrees Fahrenheit), far hotter than that of the photosphere and chromosphere. The reason for this is unknown; as far as we are aware, atoms tend to move from high to low temperatures and not vice versa, so the process of material moving out of the Sun beyond the photosphere is not understood.

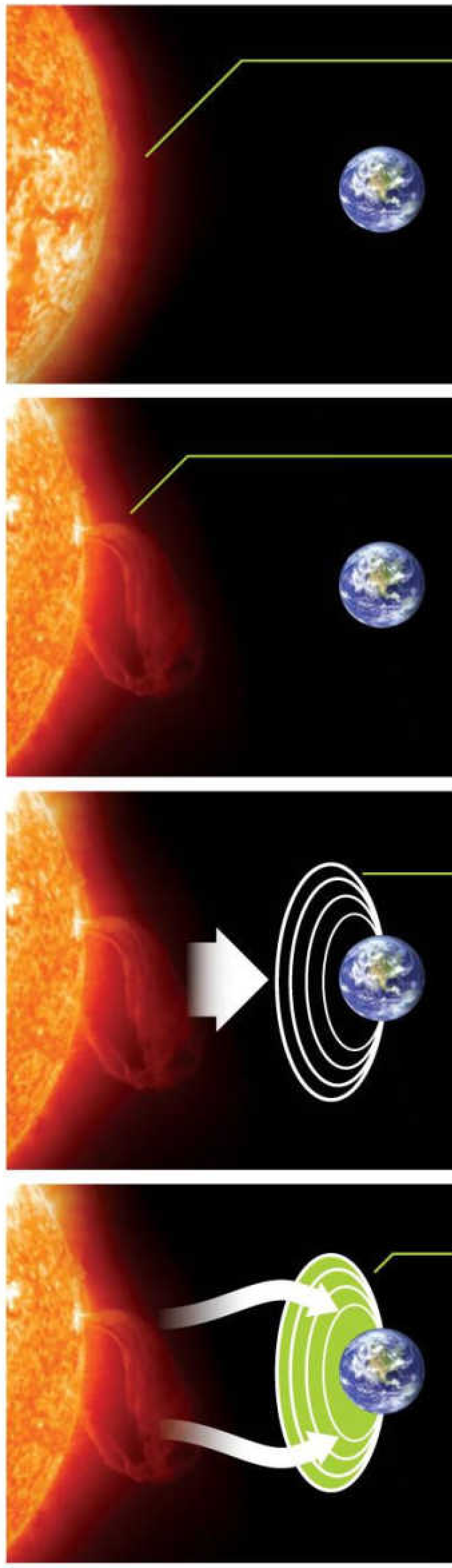
On the photosphere, dark and cool regions known as sunspots appear in pairs as a result of intense magnetic fields. The magnetic fields, caused by gases moving in the Sun's interior, leave one sunspot and enter another. Sunspot activity rises and falls on an 11-year cycle, as discussed in the next section. Sometimes clouds of gases from the chromosphere will follow these magnetic field lines in and out of a pair of sunspots, forming an arch of gas known as a solar prominence. A prominence can last up to three months and may extend up to 50,000 kilometres (30,000 miles) above the surface of the Sun. Once they reach their maximum height they break and erupt, in turn sending massive amounts of material racing outwards through the corona, an event which is known as a coronal mass ejection (CME).

When the sun's magnetic field is concentrated in sunspot areas, the resultant magnetic field lines can extend and snap, causing a violent explosion on the surface of the Sun called a solar flare. At the moment of eruption vast amounts of radiation are emitted into space, which we call a solar storm when it reaches Earth. The particles within a solar storm often interact with particles in the atmosphere of planets in the Solar System, causing fantastic displays of light at their poles as the gases in the planet's atmosphere are heated by the particles. On Earth we know these as the aurora borealis in the Northern Hemisphere and the aurora australis in the Southern Hemisphere.



How solar storms work

Vast amounts of radiation heading for Earth



Explosion
A solar flare can release up to 6x10^25 joules of energy as it explodes from the surface of the Sun. The giant clouds of radiation and particles can take up to two days to travel to the Earth.

Cycle
Solar flares peak in 11-year-long activity cycles. The cause of these cycles is unknown. In periods of inactivity there can be less than one flare a week but when the Sun is at its busiest there can be several every day.

Intensity
Solar wind typically travels at 1.6 million kph (one million mph), but the explosive event that emits a solar flare can send it hurtling towards the Earth up to four times faster.

Magnetosphere
The magnetic field surrounding the Earth acts as a barrier from the Sun's activity, but some of the particles travel along the magnetic field lines and excite particles in our atmosphere, in turn causing auroras to form at the poles.

The solar cycle

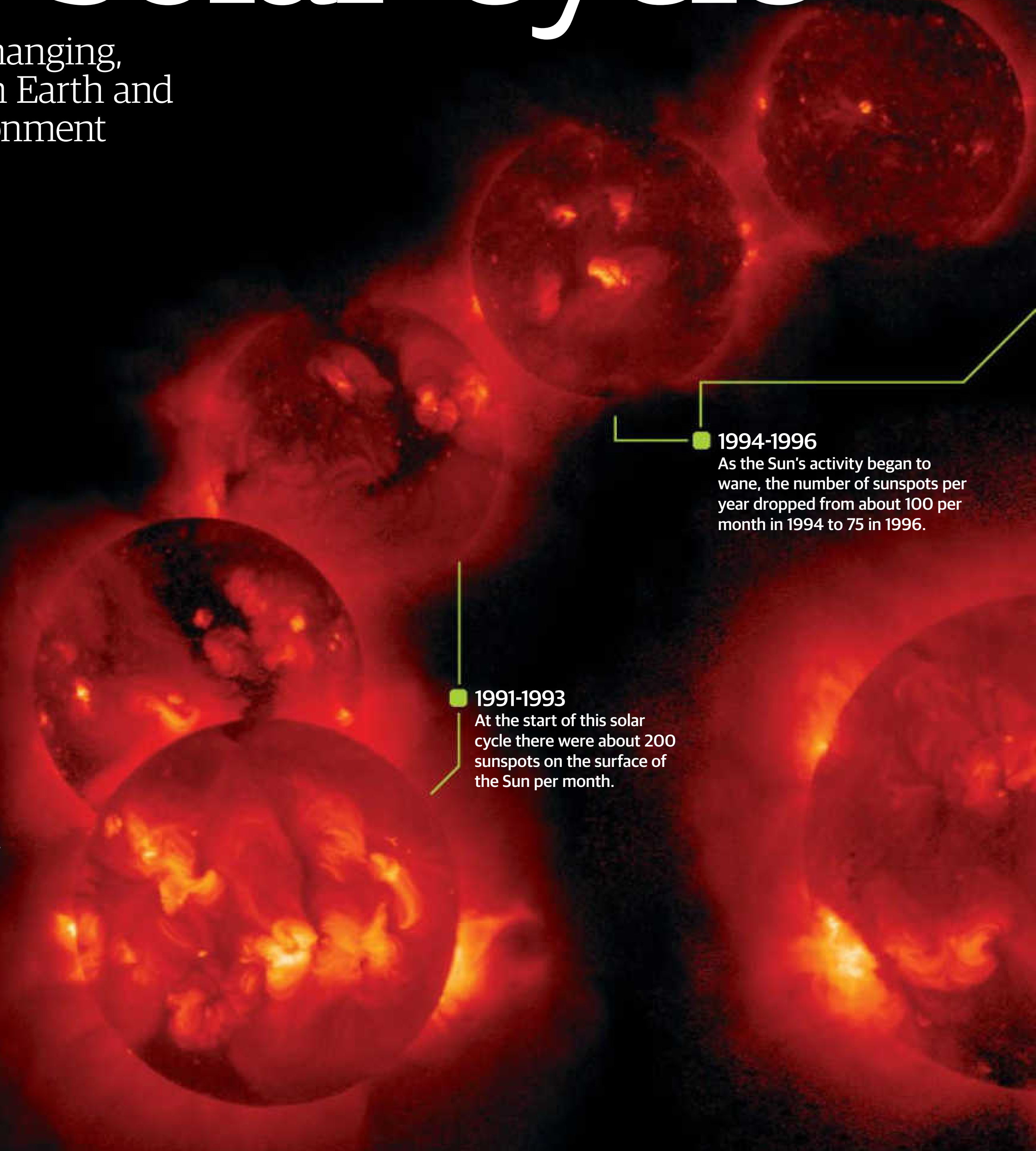
Our Sun is ever-changing, affecting all life on Earth and our natural environment

Our Sun may be a great distance away but its fluctuations and perturbations are still felt here on Earth.

Every 11 years the Sun moves from a period of low activity, known as a solar minimum, to a period of high activity, known as a solar maximum, and back again. When it is at its most active the Sun is even more violent than usual, with a greater number of sunspots appearing on its surface and therefore more solar flares emitted into space. During its minimum point it is still a raging inferno firing material into space but, by comparison, it is much quieter and sunspots, and therefore solar storms, are rare.

Cycles are observed by monitoring the frequency and position of sunspots on the Sun. When the Sun reaches the end of its cycle, new sunspots will appear near the equator. The beginning of the next cycle will see sunspots appear at higher latitudes on the surface of the Sun.

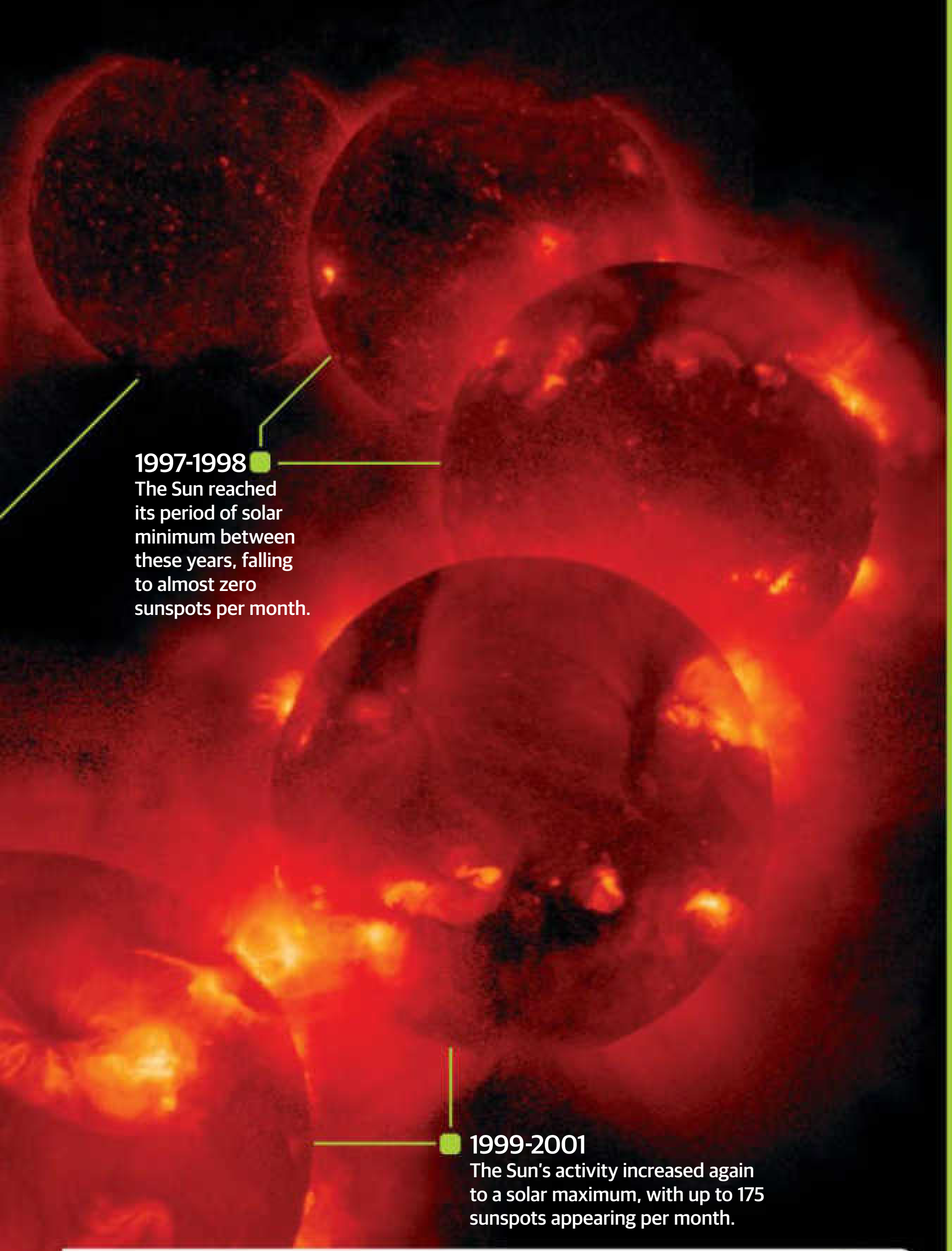
Solar cycles have been observed for centuries, but a standardised method of counting them was not devised until 1848 when Johann Rudolf Wolf started counting sunspots on the solar disk and calculated the Wolf number, which is still used today to keep track of the solar cycle. Cycles vary in their intensity. From 1645 to 1715 there were few sunspots present on the Sun, a period known as the Maunder Minimum. The number of sunspots has been relatively more uniform this century, with cycles having an average period of 10.5 years. The Sun also has a 22-year magnetic cycle where, every 22 years, its magnetic field flips from pole to pole. This doesn't have a noticeable effect on the Solar System, but indicates when the solar maximum of the current cycle has been reached. However, the reason for these cycles remains a mystery. No one yet has any clear understanding as to why the Sun has periods of varying activity.



10 years of the Sun

These X-ray images were taken by Japan's Yohkoh Solar Observatory and show the changes in the Sun's corona over a ten-year cycle between 30 August 1991 and 6 September 2001

"Solar cycles have been observed for centuries, but a method of counting them was not devised until 1848"



1997-1998
The Sun reached its period of solar minimum between these years, falling to almost zero sunspots per month.

1999-2001
The Sun's activity increased again to a solar maximum, with up to 175 sunspots appearing per month.

The Scientist's view

How we understand solar cycles

"Sun-Earth interaction is complex, and we haven't yet discovered all the consequences of solar cycle variation on Earth's environment. We saw a large amount of geomagnetic activity driven by recurring fast solar wind streams during the recent solar minimum. A surprising departure from the consistently low activity we'd come to expect from previous minima, especially considering the record low level of sunspots. These new observations deepen our understanding of how solar quiet intervals affect the Earth and how and why this might change from cycle to cycle."

Sarah Gibson, UCAR, @AtmosNews

The Sun by numbers

Fantastic figures and surprising statistics about our nearest star

99.86%

The Sun's percentage of mass of the entire Solar System

Less than 5% of stars in the Milky Way are brighter or larger than the Sun

1 million Earths
Would fit inside the Sun

164 watts
Is the amount of energy every square metre of the Earth's surface receives. That's the equivalent of a 150-watt table lamp on every square metre of the Earth's surface

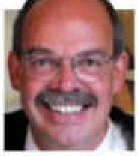
498 seconds
How long it takes light to travel from the Sun

100 BILLION
TONS of dynamite would have to be detonated every second to match the energy produced by the Sun

The SOHO mission

The Solar and Heliospheric Observatory was launched in December 1995 and is helping us explore the Sun

Interview



SOHO project scientist Bernhard Fleck tells us why studying the Sun is important to Earth

1. Understand life
"The Sun provides the energy for all life on Earth. It seems quite natural that we are curious to know more about the star from which we live."

2. Understand climate
"Solar radiation is the dominant energy input into the terrestrial ecosystem. The Sun provides a natural influence on the Earth's atmosphere and climate. To understand mankind's roles in climate change, the Sun's impact must be understood."

3. Predict space weather
"Our Sun is very dynamic and produces the largest eruptions in the Solar System. These solar storms can reach our planet and adversely affect technologies such as satellites and power grids. Space weather becomes increasingly important as our society depends more on modern technologies."

4. Learn about stars
"If we want to understand the universe, we have to understand the evolution of galaxies. To understand galaxies, we need to understand the evolution of stars that make up the galaxies. If we want to understand stars, we better understand the Sun, the only star we can resolve in great detail."

5. Stellar physics lab
"The Sun lets us study basic physical plasma processes under conditions that can't be reproduced on Earth."

The Solar and Heliospheric Observatory, also known as SOHO, was launched on 2 December 1995. It was built in Europe by prime contractor Matra Marconi Space, which is now EADS Astrium. The spacecraft is operated jointly by the ESA and NASA. It studies the Sun in depth, all the way from its deep core to its outer corona and its solar wind.

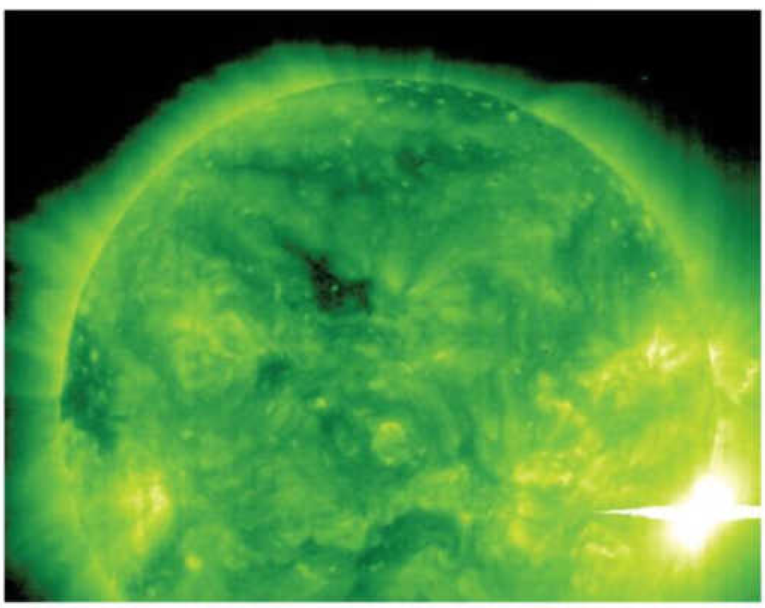
SOHO is made of two modules, the Service Module and the Payload Module. The former provides SOHO with power, while the latter houses all of the instruments on the spacecraft. Overall, there are 12 instruments on board SOHO, nine of which are run by Europe as well as three from the United States.

SOHO is located near to Lagrangian point 1, which is a point between the Earth and the Sun about 1.5 million kilometres (930,000 miles) from our planet. It is the point where the gravitational attraction of the Sun and the Earth cancel out, so a telescope such as SOHO can remain in a stable orbit to observe the Sun. SOHO is one of the only telescopes currently capable of detecting incoming solar flares that could be potentially hazardous to satellites and other electronics on Earth.

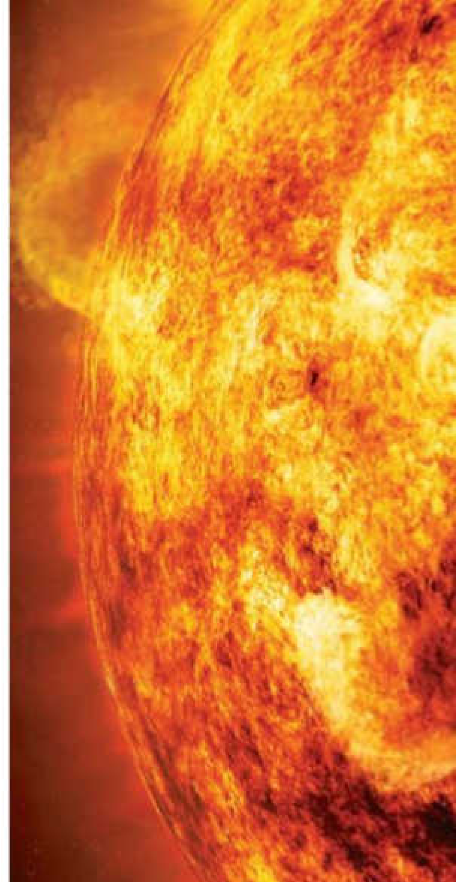
Of the 12 instruments on board SOHO one of the most interesting is the Large Angle and Spectrometric Coronagraph (LASCO), which studies the Sun's corona by creating an artificial solar eclipse. The LASCO instrument has been largely responsible for inadvertently discovering many comets near the Sun, with over 1,800 found to date.

SOHO has three primary objectives that it has been carrying out since its launch. One of these was to investigate the outer regions of the Sun, specifically the corona.

At the moment it is still unknown why the corona is hotter than the photosphere and chromosphere of the Sun, so it is hoped that SOHO might help to provide the answer in the future. SOHO has also been used to observe the solar wind, and also to study the interior structure of the Sun through a process known as helioseismology.



On the scale of solar flares, X-class storms are most powerful. SOHO took this image on November 2003 showing the most powerful ever recorded, which reached X28



Take a tour of SOHO

SOHO is made up of two modules. The Service Module forms the lower portion, while the Payload Module sits above

Payload Module
This sits on top of the Service Module and houses all 12 of the instruments on board the spacecraft.

Service Module
The Service Module provides power, telecommunications, thermal control and direction to the spacecraft.

Malfunction
In 1998 SOHO suffered a major malfunction that almost rendered it unusable. However, some smart thinking enabled scientists to regain control of the telescope, although it now operates without the help of its gyroscopes, the only three-axis stabilised spacecraft to do so.

Mission Profile

Solar and Heliospheric Observatory (SOHO)

Mission dates: 02/12/95-12/12/14

Details: SOHO is a joint project between the ESA and NASA. It was designed to study the origin of the solar wind, the outer atmosphere of the Sun and its internal structure. SOHO has found over 1,800 comets to date and discovered that quakes on the Sun's surface are caused by solar flares. It has also made the most detailed map of features on the solar surface.

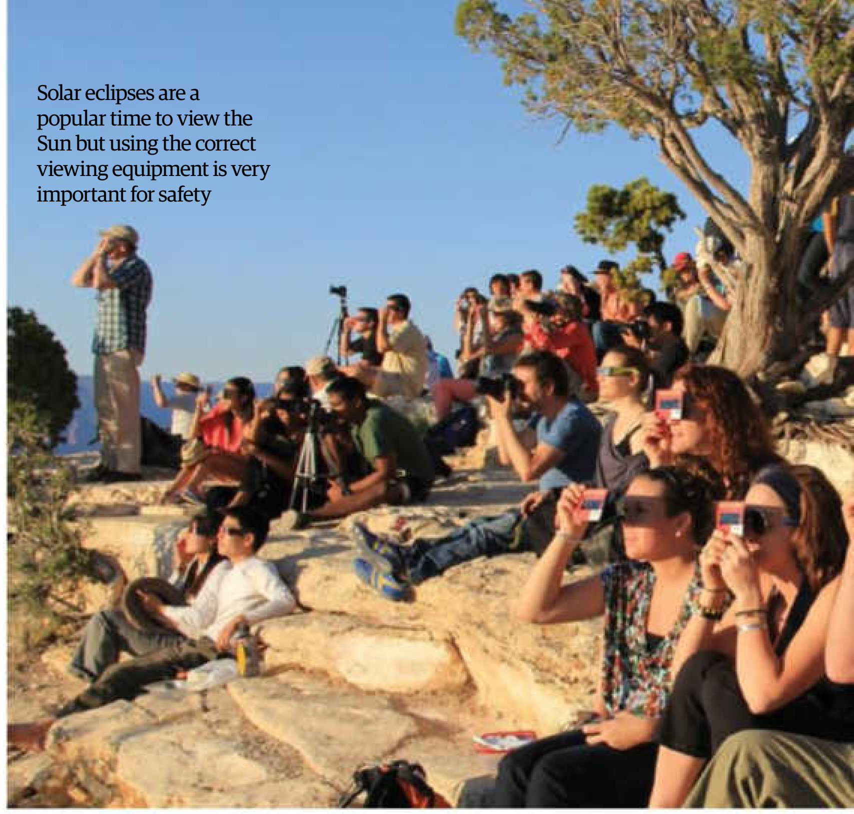
Antennas
SOHO transfers data back to Earth at a rate of between 40Kbits/s and 200Kbits/s using its high and low gain antennas.

Solar panels
SOHO's only source of energy is from the Sun, but as it is in orbit around it, it has a large supply of energy.

LASCO
SOHO's Large Angle and Spectrometric Coronagraph (LASCO) produces detailed imagery of the solar corona by creating an artificial eclipse.

The SOHO spacecraft has survived 17 years in space, 15 more than its initial mission length

"SOHO is located near to Lagrangian 1, which is a point between the Earth and the Sun about 1.5 million km (930,000 miles) from our planet"



Solar eclipses are a popular time to view the Sun but using the correct viewing equipment is very important for safety

Observing the Sun

Humanity has been fascinated by the Sun for thousands of years and even primitive records still prove useful. Discover more about the past, present and future of studying the Sun

Observations of the Sun have been used for both scientific and religious observations for millennia. Civilisations have used the Sun to keep an accurate count of days, months and years since at least 300BC, while scientists such as Galileo studied the Sun through telescopes to discern some of its characteristics.

At the Chankillo archaeological site in Peru can be found the oldest solar observatory in the Americas, a group of 2,300-year-old structures used to track the motion of the Sun known as the Thirteen Towers. These towers provide a rudimentary solar calendar through which the Sun can be traced.

The towers, each between 75 and 125 square metres (807 and 1,345 square feet) in size, run from north to west along a ridge along a low hill. From an observation point to the west of the ridge the Sun can be seen to rise and set at different points along the ridge, which allowed ancient civilisations to track the number of days it takes the Sun to move from tower to tower.

Much later, in 1612, the renowned Italian astronomer Galileo Galilei (1564-1642) used his telescope to make one of the first observations of sunspots on the surface of the Sun. In 1749 daily observations began at the Zurich Observatory and, since 1849, continuous observations have been made to count the number of sunspots present on the Sun's surface at any one time.

Fast forward to today and, aside from SOHO, one of the primary telescopes used to observe the sun is the Japanese Hinode spacecraft. Hinode is a telescope in sun-synchronous Earth orbit, which allows for nearly continuous observation of the Sun. It was launched on 22 September 2006 and was initially planned as a three-mission study of the magnetic fields of the Sun, but its mission has since been extended as it continues to operate nominally.

Another important Sun-observing telescope is the Solar Dynamics Observatory (SDO), launched by NASA in 2010. The goal of the SDO is to study the influence of the Sun near Earth, predominantly how the Sun's magnetic field is responsible for the solar wind once it is released into the heliosphere. It should help scientists further understand the Sun's influence on the Solar System.

In the future, NASA's Solar Probe Plus will be the closest spacecraft to the Sun, approaching to within just 8.5 solar radii (5.9 million km, 3.67 million miles, 0.04 AU) after its launch in 2018. It will probe the outer corona of the Sun in unprecedented detail, while also becoming the fastest spacecraft of all time in the process at up to 200km per second (120 miles per second).

Apart from million dollar telescopes, many amateur astronomers around the globe today observe the Sun either for entertainment or educational benefit. Using specially designed glasses people can look at the Sun from Earth, although caution must be taken to limit time spent looking at the Sun and it should never be looked at with the naked eye. Other methods of solar observation include using a telescope to produce a trace of the Sun, a method similar to that used by Aristotle and his camera obscura in the 4th Century BC. Again, precautions must be taken here, as under no circumstances should the Sun be directly observed through a telescope.

Whatever the method, and whatever the mission, observations of the Sun have been a long tradition and will continue to be so for the foreseeable future. Astronomical events such as planetary transits and solar eclipses provide amateur astronomers with opportunities to see extraordinary solar phenomena, while agencies throughout the world will continue to study the Sun and learn more about how the fantastic star works.

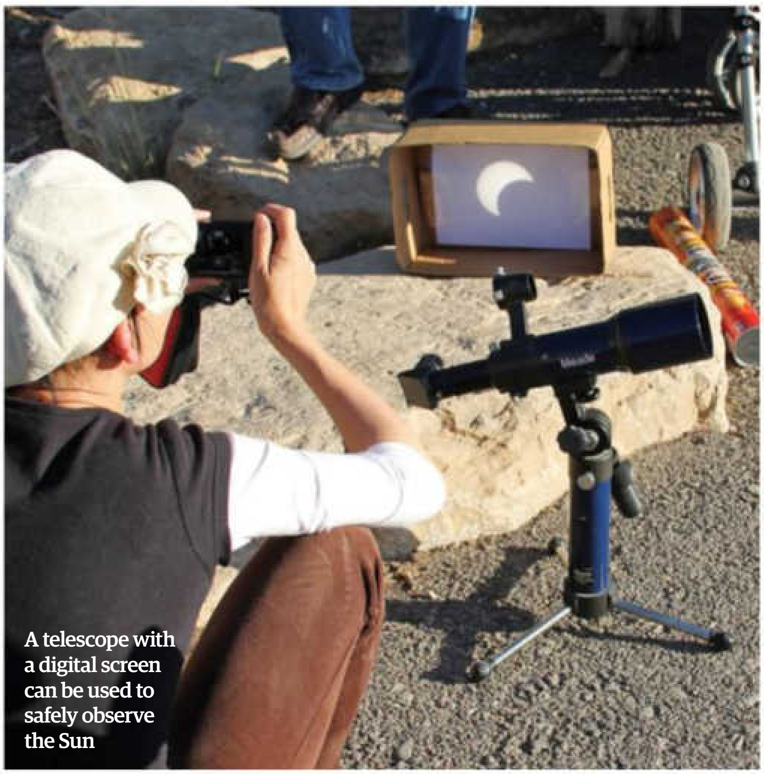
> "Civilisations have used the Sun to keep an accurate count of days, months and years since at least 300BC"

The history of observing the Sun

400BC
The world's oldest solar observatory, the Thirteen Towers of Chankillo, is built in Peru to track the motion of the Sun.

350BC
Aristotle uses a camera obscura to project an image of the Sun and observe a partial eclipse.

1612
Galileo Galilei uses his telescope to make one of the first observations of sunspots on the surface of the Sun.



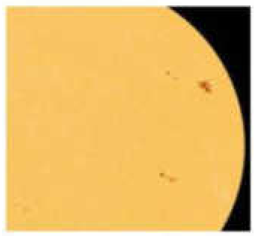
A telescope with a digital screen can be used to safely observe the Sun

Different ways to observe the Sun

On Earth we perceive the Sun to be a yellow ball of gas in the sky but, like anything as hot as the Sun, it is actually closer to being white hot when viewed from space. There are several telescopes currently observing the Sun but the large majority of our images come from the STEREO telescope and the SOHO observatory, both in orbit around the Sun. By viewing the Sun in different wavelengths we can study its different characteristics and see some of its main features in a different light.

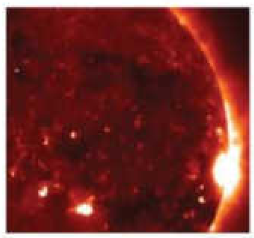
Ultraviolet

Images of the Sun in ultraviolet light are between wavelengths of about 19.5 and 30.4 nanometres. Such an image of the Sun is at the lower end of this scale, and allows us to see where the lower part of the corona and upper part of the chromosphere combine. The light in this image comes from active regions in the Sun's chromosphere.



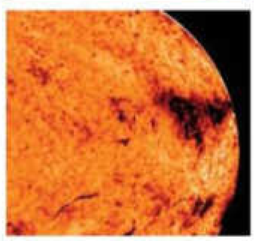
Visible

Visible light images commonly refer to those viewing the Sun in white light, which shows the true colour of the white-hot Sun. In visible light images we can see the Sun's photosphere, which is about 6,000 degrees Celsius (10,832 degree Fahrenheit) and therefore appears white-hot. Here, we can see dark spots on the surface of the Sun, known as sunspots.



X-ray

Light with a wavelength shorter than ten nanometres (ten billionths of a metre) is known as X-ray light. X-rays are emitted from the Sun's corona, the hottest visible layer of the Sun's atmosphere. The visible areas of brightness are places where more X-rays are being emitted, around areas of increased activity on the Sun's surface.



Infrared

Infrared light is responsible for more than half of the Sun's power output, typically around wavelengths of 1,080 nanometres. Infrared images show features of the Sun's chromosphere and corona. The dark features on the image are areas where the gas is more dense, absorbing more infrared light than in other areas.

1749
Daily observations of the Sun begin for the first time at the Zurich Observatory in Switzerland.

1849
New observatories around the world allow continuous observations of sunspots to be made.

2006
The Japanese telescope Hinode is launched to study the magnetic fields and atmosphere of the Sun.

2010
NASA launches the Solar Dynamics Observatory, its primary goal being to study the influence of the Sun near Earth.

2018
NASA's new Sun-observing telescope Solar Probe Plus will launch and become the closest spacecraft to the Sun.

The Moon

The most visible celestial object from Earth has been the source of human fascination for millennia, yet we're still discovering more about it all the time

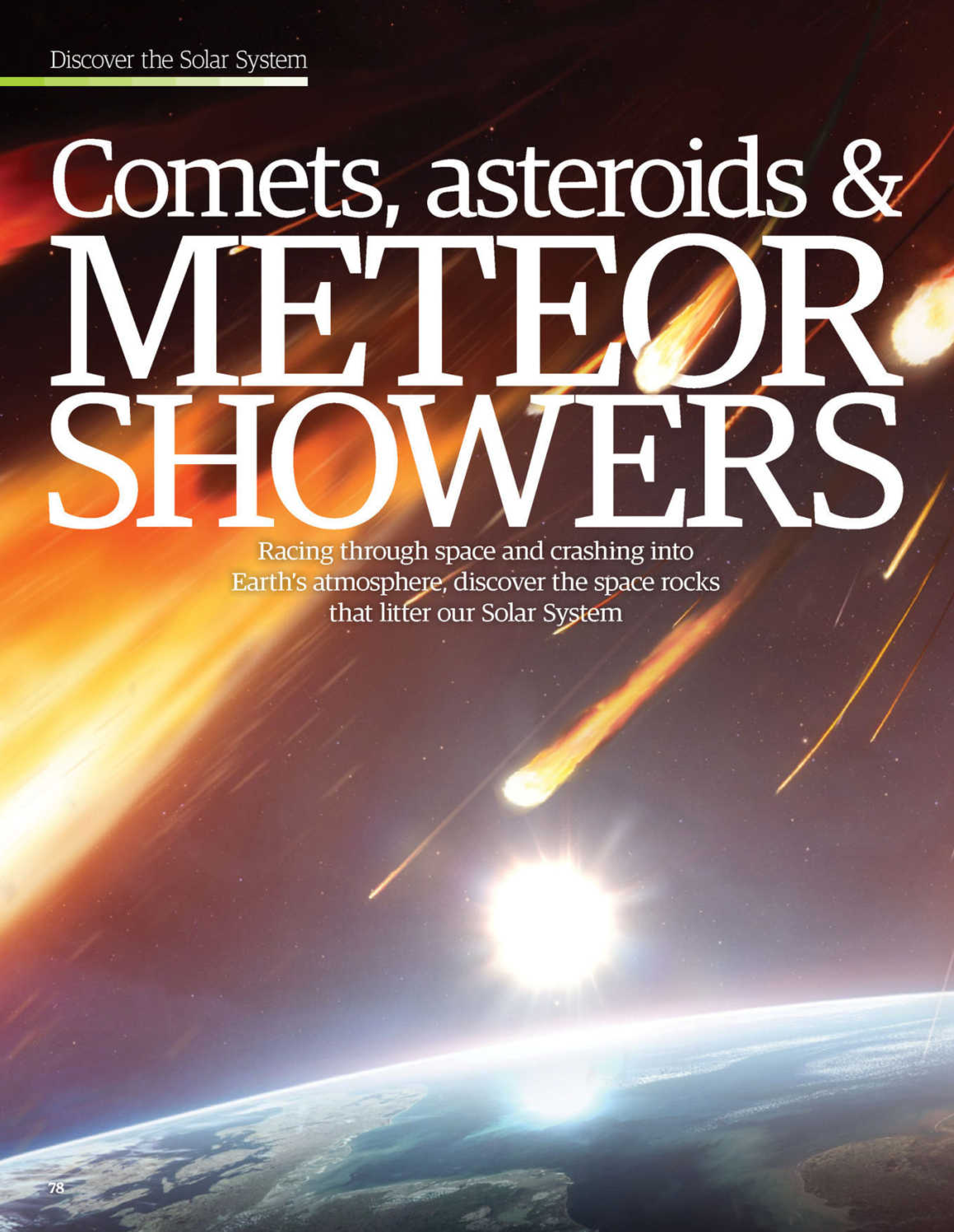
Orbiting at a distance of anywhere between 362,570 kilometres and 405,410 kilometres (225,000 to 252,000 miles) and moving away from the Earth at almost four centimetres (1.57 inches) per year, all 74 billion trillion kilograms (160 billion trillion pounds) of blasted grey rock that is the Moon never fails to make for fascinating viewing. Its topography is a pattern of 'maria' – impact basins once filled with lava – and giant craters that are clearly visible from Earth.

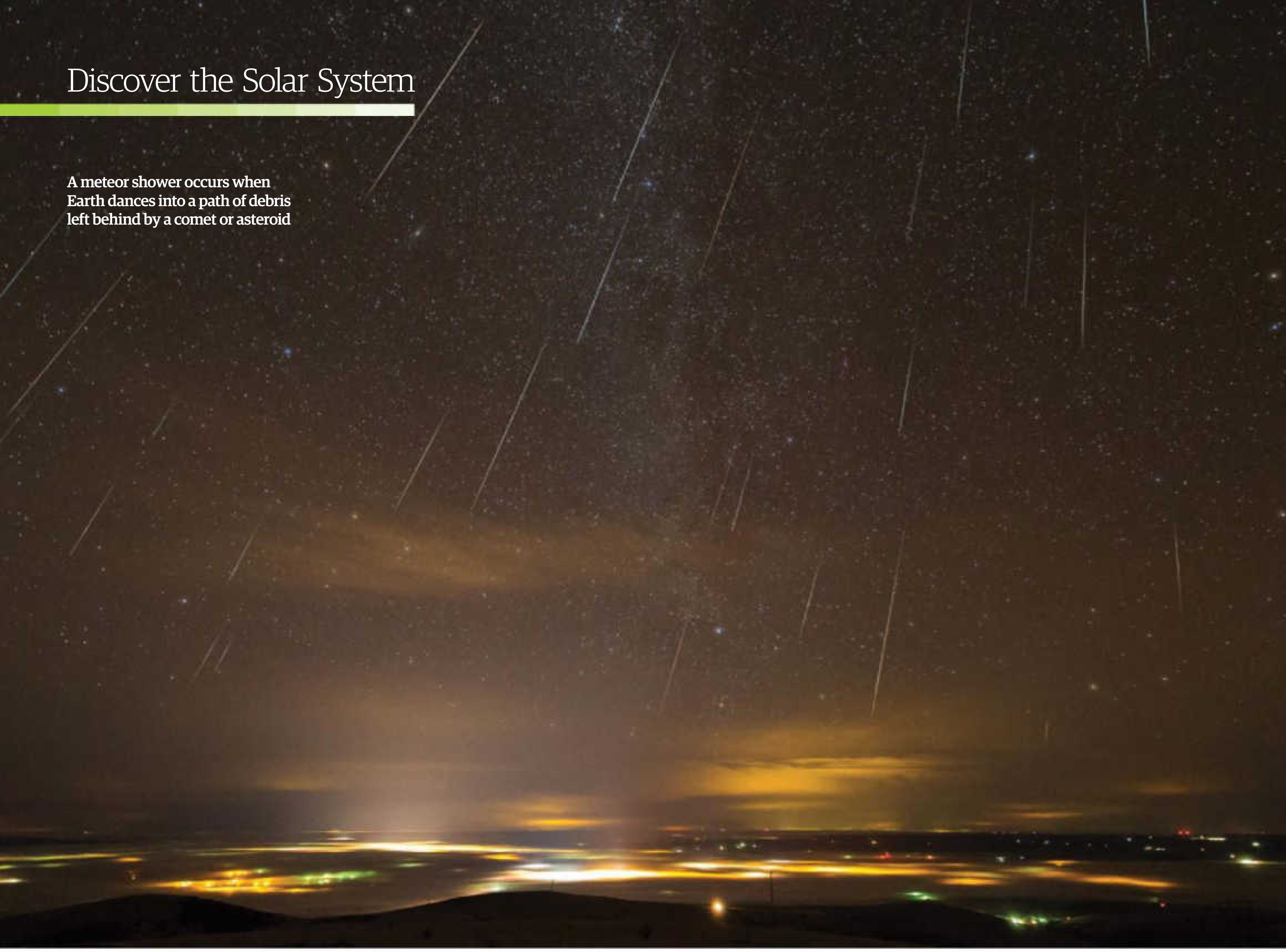
Most notable of these is Tycho on the near side of the Moon. Despite being around 86 kilometres (53 miles) in diameter and 4.8 kilometres (three miles) deep, it's not the largest of the Moon's impact features: that accolade goes to the South Pole-Aitken basin on the far side, which is 2,500 kilometres (1,550 miles) in diameter, 13 kilometres (eight miles) deep and one of the biggest craters in the Solar System. But with its distinctive ray system fanning out for hundreds of kilometres across the surface in all directions, Tycho is the Moon's most recognisable feature.

We're still learning about the Moon, the most recent major mission being the Gravity Recovery and Interior Laboratory (GRAIL) mission that generated the highest resolution gravity map of any celestial body.

Comets, asteroids & METEOR SHOWERS

Racing through space and crashing into Earth's atmosphere, discover the space rocks that litter our Solar System





A meteor shower occurs when Earth dances into a path of debris left behind by a comet or asteroid

Every 133 years a comet that goes by the name of Swift-Tuttle makes its return to the inner Solar System. It last made an appearance 15 years ago. Each time it nears the Sun this speeding ball of ice, rock and dust grows a tail that deposits a glittering trail in its wake, replenishing it on each visit.

Every year, our very own planet moves through this cloud, causing those dust particles to come crashing through the atmosphere. Most of them are tiny, just centimetres or even millimetres across, but as they burn up 100 kilometres (60 miles) above our heads they leave a bright streak of light. We call this a meteor, although you may know them by their more common name of 'shooting star'. The space between the planets and around Earth's orbit is full of dust, so every night there will be one or two random meteors. But when the Earth travels through the cloudy trail of dust left by a comet such as Swift-Tuttle, there are so many meteors that it is described as a meteor shower. If you have ever seen one, then you'll know that meteor showers are among the most spectacular sights in the entire night sky.

There are many meteor showers each year, some better than others. The dust left by Swift-Tuttle forms the Perseid meteor shower, which is a great summertime meteor shower that runs from 17 July to 24 August each year. However, each meteor shower has a peak, which is a time when the shooting stars falling through the sky occur in their greatest number. For the Perseid meteor shower this peak occurs on 12 and 13 August. Either side of this peak, the number of meteors drops off. You can understand the reason for this if you imagine the trail left by the comet beginning to spread out. The peak coincides with the densest part of the trail and the most active meteor showers can produce more than 100 shooting stars per hour.

Other great meteor showers include the Quadrantids in January with the peak on the 3 and 4 of the month; the Lyrids between 16 and 26 April; the Orionids that peak on 21 October; the Leonids that are at their maximum between 17 and 18 November; and the Geminids, which are at their best on 13 and 14 December. The names of the meteor showers come from the constellations in which they appear to streak from – this is the direction in which Earth is moving through the dust trails. For example, the Perseids streak across the sky from their 'radiant' in Perseus, the Leonids from Leo and the Geminids from Gemini.

Speaking of the Geminids, they are actually unique among meteor showers. All the rest are produced by dust from comets, but the Geminids are produced by dust left by an asteroid, known as 3200 Phaethon. This goes to show that sometimes the lines between asteroids and comets can be blurred. Astronomers have even witnessed some asteroids in the asteroid belt acting like comets, by growing a tail.

This is why wrapping up warm, going outside, looking up and counting meteors is scientifically important. Differences in the speed, direction, brightness and colour of meteors can tell us a lot about the nature of the object that produced them. For example, Geminid meteors tend to move more slowly than meteors left by comets and they burn up at a much lower altitude of about 38 kilometres (24 miles) above ground.

Occasionally, a meteor entering the atmosphere is a little larger than the rest. Rather than just leaving the thin streak of a shooting star, they are bigger and brighter, sometimes even brighter than Venus. These are fireballs that are burning up lower in the atmosphere. The brightest fireballs are called bolides

> "It flattened the trees for hundreds of miles around. Now that is a city-destroyer" **Dr Brian May, Asteroid Day**

Naming space rocks

Depending on their size, what they're made of and whether they're inside or outside the Earth's atmosphere, space rocks take on a new name

Comet
These bodies are made of ice, rock dust and frozen gases. Comets have a nucleus and show off a brilliant tail when they get closer to the Sun. As they disintegrate, some comets leave a trail of solid debris. A comet's nucleus ranges from 16-60km (9.9-37mi), while their tails can stretch for hundreds of millions of kilometres.

Meteoroid
A small rocky or metallic body that races through space, meteoroids are quite a lot smaller than their larger cousins, the asteroids. They range in size from small grains to 1m (3.3ft) wide chunks of rock. Lumps of space rock that are even smaller than meteoroids are classified as micrometeoroids or space dust.

Meteor showers
These occur at the same time every year, when the Earth passes through a region that has a large concentration of debris shed from either a comet or an asteroid. From our location on Earth, meteors appear to originate from the same location year after year.

Asteroid
Any large lump of space rock that ranges in size from 1m (3.3ft) to hundreds of km, is an asteroid. They often pass our planet and are found, most commonly, in the asteroid belt between Mars and Jupiter.

Meteor
The streak of light that's thrown out by a meteoroid or an asteroid as it enters the atmosphere at high speed. The brightness comes about as the rock rubs against air particles to make friction, which heats the meteors.

Fireball
This is another term for a very bright meteor. If you ever see a fireball streaking through the night sky, then you will quickly notice its bright white to orange hue outshines that of the brightest planet in the sky, Venus.

Meteorite
If a piece of a meteoroid or an asteroid manages to survive its passage through the atmosphere and touches down on the ground, then we call this piece of space rock a meteorite. Meteorites can weigh in at anything from a few grams up to dozens of tons.

Bolide
Similar to fireballs, however in this instance, their brightness is likened to that of a full Moon and even brighter. Bolides often explode in the atmosphere.

How the Chelyabinsk meteor hit Earth

1 Origin
The Chelyabinsk meteor was a 20m (66ft) wide asteroid known as an Apollo asteroid, which spends most of its time inside Earth's orbit, closer to the Sun.

2 Unseen danger
Since the meteor came from the southeast, out of the glare of the Sun, it effectively approached us in our blind spot, where our ground-based telescopes cannot look.

3 Fireball
It entered the atmosphere at about 9.20am Yekaterinburg Time (YEKT) on 15 February 2013 at a velocity of 19km/s (12mi/s). It glowed so brightly that, to the people of Chelyabinsk, it looked brighter than the Sun.

4 Airburst
At a height of 30km (18mi) off the ground, the asteroid exploded with the energy of 500 kilotons of TNT. A ball of extremely hot dust and gas continued to push a further 3.2km (2mi) into the atmosphere before dissipating.

5 Caught on camera
Because so many drivers in Russia have dashboard cameras, most of the footage of the fireball came from people driving to work, or from security cameras.

6 Delayed shock wave
People on the ground saw the light and the smoke trail left by the fireball, but because light travels faster than sound, they heard nothing until nearly two minutes later.

7 Injuries
Almost 1,500 people were injured, mostly by flying glass as the shock wave shattered windows. This is by far the highest number of injuries caused by a meteor.

8 Crater
Although the meteor was mostly destroyed in the explosion, fragments did reach the ground as meteorites, where a piece crashed into a frozen lake.

On 15 February 2013, a meteor with a mass of around 13,000 tons exploded above the Chelyabinsk region of Russia

– if you're lucky enough to see one, you might even see chunks breaking off, on fire. Meteors around 20 or 30 metres (66 to 98 feet) in size will explosively fragment in the atmosphere, causing an airburst like the dramatic event that occurred over the Russian city of Chelyabinsk in 2013. This exploded 30 kilometres (18 miles) above the ground and the shock wave shattered windows, damaged roofs and sent 1,500 people to hospital with cuts from flying glass.

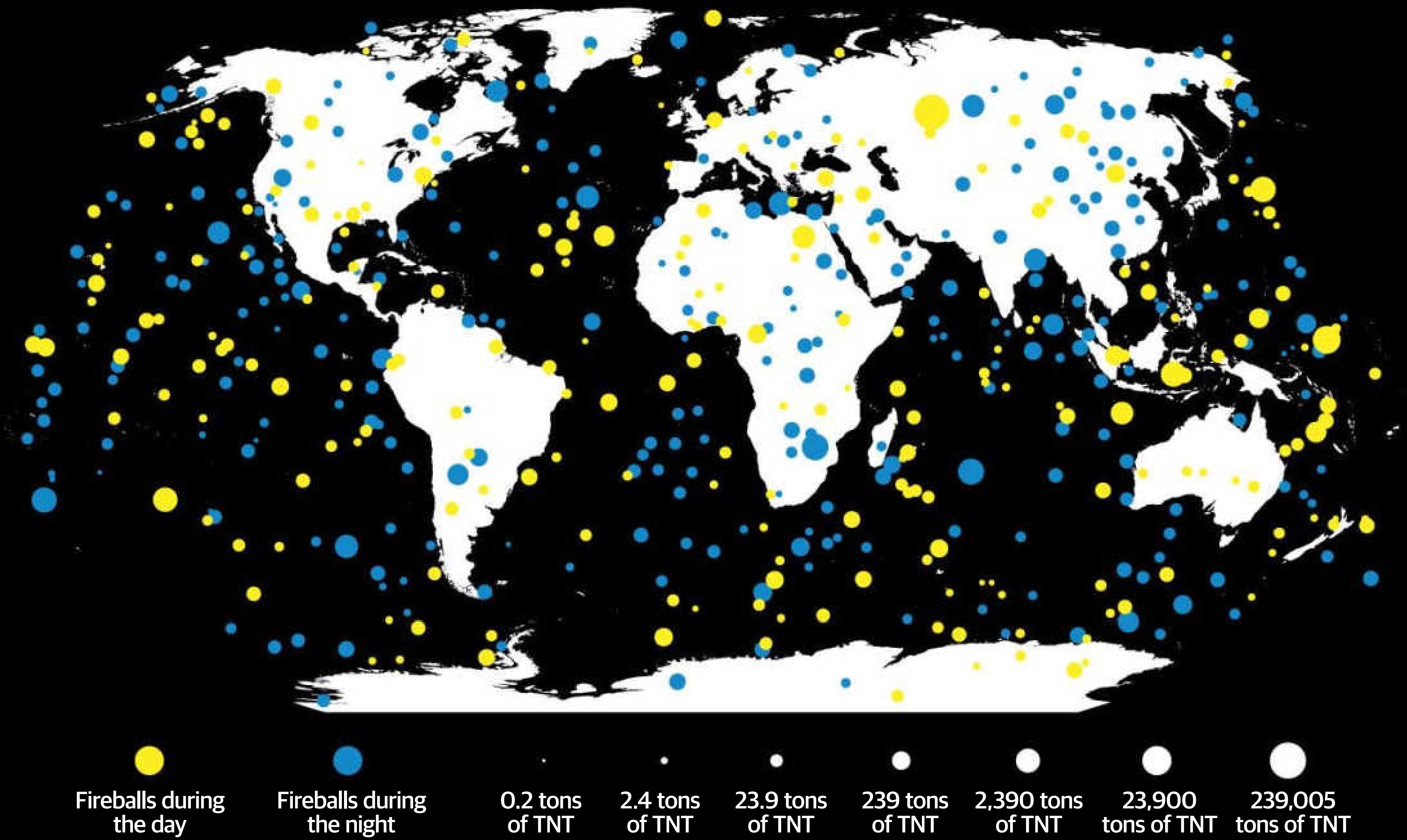
The biggest meteors can actually reach the ground before they completely disintegrate. When they do, we call them meteorites and over 61,000 of these have been found on Earth. Most of them are chunks of rock smaller than your hand and the most common place to find them are in the white, icy landscape of Antarctica or the barren desert. Here, the charred and pitted black rocks on the ground stand out like a sore thumb. Not all meteorites come from asteroids either – a handful come from the Moon and Mars. Space agencies like NASA talk about launching sample-return missions, where a robot will visit a celestial body and bring back a chunk of the asteroid for examination on Earth. For example, NASA's OSIRIS-REx mission that launches next year will return a sample from an asteroid to Earth. But meteorites are natural sample return missions, bringing pieces of other celestial bodies to Earth. Of course they're not pristine, having been blasted into space, probably as the result of an impact, before being burned in the atmosphere and landing on the ground on Earth. But they can tell us a great deal about the geology and chemistry of planets and asteroids. There has been some speculation that some of the 132 meteorites from Mars contain evidence for life in the form of microbial fossils. This was a claim made by NASA scientists in the Nineties after examining a meteorite from Mars called ALH 84001, which was found in the Allan Hills region of Antarctica in 1984. Unfortunately, most scientists are now convinced that the microscopic features are not fossils at all, or if they are then they are fossils of microbes from Earth that contaminated the meteorite while it lay on the ice in Antarctica.

Meteorites can also tell scientists plenty about the dawn of the Solar System and the birth of our blue planet Earth. This is because many meteorites represent debris leftover from the distant era when the planets were forming 4.5 billion years ago. They are broadly split into three types: stony meteorites, iron meteorites and a mixture of the two. Stony meteorites, especially a specific type called chondrites, make up the vast majority of meteorites and are the same type of rock that built planets like Earth. They are very primitive, having never really melted and so they preserve the chemical building blocks of the planet-forming disc that surrounded the young Sun. The other type of stony meteorite are called achondrites and these have melted, either in the impacts that blasted them off their original asteroid, or when they were buried deep inside a large asteroid where conditions were hot. So achondrites are special because they tell us about the chemical conditions within large asteroids and the protoplanets similar to those that eventually became the real planets.

Iron meteorites also come from the cores of protoplanets, because that's where all the iron sank

20 years of fireballs

Between 1994 and 2014, our planet has been bombarded by small space rocks, some of which have exploded with the force of thousands of tons of explosives




Brian May was part of Asteroid Day, an effort to make us more aware of dangerous asteroids

to when they formed. Iron meteorites are incredibly hard and dense, but only a twentieth of all meteorites are of this variety. Meanwhile, there are two different types of stony-iron meteorite, called pallasites and mesosiderites. Pallasites are recognisable thanks to their large crystals of a green mineral called olivine. Mesosiderites are more of a jumble of rock and metal, which are made when two asteroids collide in space, the impact fusing different materials together.

On rare occasions, a really big meteor will enter Earth's atmosphere. These are sometimes big enough to blow out large craters, or explode over towns and cities causing harm. A hundred years before the Chelyabinsk meteorite, a similar airburst flattened 80 million trees in Tunguska, a remote region in Siberia.

These events worry scientists who fear that one day an asteroid will hit us that could destroy a city or worse, send so much dust into the air that it will block the Sun and end life on Earth. It's a big concern to Queen founder Dr Brian May, who recently lent his support to the Asteroid Day event, to raise awareness about this threat: "30 June was the anniversary of Tunguska in 1908. Not a huge object but it exploded before it hit the ground... which flattened the trees for hundreds of miles around. Now that is a city destroyer, the force of a thousand atom bombs."

To help forewarn us, NASA's Spaceguard programme has found over 90 per cent of asteroids larger than a kilometre in size that come close to Earth. These are the real killers, like the asteroid that wiped out the dinosaurs 65 million years ago. However, there are still millions of asteroids out there that have not been discovered that are smaller than 100 metres (328 feet) but could still do serious damage. This is why Asteroid Day was held on 30 June this year and headlined by Brian May on the anniversary of the Tunguska explosion. It reminded us that we still have much to do to protect ourselves from asteroids. A new space telescope, called Sentinel, is to be launched by the B612 Foundation, which is led by former astronauts dedicated to saving the Earth from asteroids. Comets can also be a danger but, because there are fewer of them, they pose less of a risk. Instead, the Earth is more likely to fly through their tails so we can see spectacular meteor showers in the sky. From shooting stars to fireballs, meteors and meteorites, their origins are all the same, just on vastly different scales.

The stream of debris left behind the Swift-Tuttle comet in August 2010

Brian May visting the Paranal Observatory in September 2015, seen here with the ESO Very Large Telescope

ESCAPE TO TITAN

When the Sun scorches the Earth, a tiny moon in orbit around the ringed giant Saturn is our next home

Humanity on Earth is doomed and there is nothing we can do about it. Our planet may have already survived for some 4.5 billion years but we face some major threats. There's always the possibility that an asteroid will wipe us out, just as one did for the dinosaurs 65 million years ago. We could be engulfed by a gamma-ray burst or disrupted by a wandering star. There are also dangers closer to home, from volcanoes to nuclear war.

But supposing humans manage to survive all such threats, we can still say for certain that life here on Earth will eventually be no more. In five billion years from now – give or take a century or two – the Sun will undergo a massive change that will fundamentally alter the make up of our Solar System. It will cause the end of not only all creatures great and small here on Earth, but possibly the entire planet, and we will have no choice other than to find somewhere else to live.

Astronomers have been looking at the possibilities of colonising other planets for a good number of years. Mars currently tops the list of destinations, with NASA working hard to develop the capabilities needed to send humans to the Red Planet in the 2030s. Yet, as interesting as that may be, some scientists are taking a much longer view. Rather than look towards the terrestrial planets for our new home, they say humans will one day have to relocate to the outer Solar System if they want to survive. As it stands, sending scores of humans to live beyond the asteroid belt is out of the question. The four gas giants are utterly unsuitable for life and the moons of the outer Solar System are well outside of the habitable zone – the region around the Sun where the atmospheric pressure is able to support liquid water at the surface, making conditions for life "just right" (the reason why it is dubbed the 'Goldilocks Zone').

Yet things can and will change. The Sun is getting gradually warmer and it will eventually become so hot that it will boil off the Earth's oceans. This will happen sooner than we think. "In around a billion years time, the Earth will probably no longer be habitable for humans," says Benjamin Charnay, a postdoctoral scientist at the Virtual Planetary Laboratory in the University of Washington. "The increasing solar insulation means the Earth will either evaporate all of its oceans or lose them by the atmospheric escape of hydrogen."

But that will only be the start. Even if humans do somehow survive the mass loss of water on Earth, the next thing to be affected would be the current habitable zone. At some stage, the Sun's hydrogen supplies at its core are going to deplete and gravity will take over. Nuclear fusion – the energy-generating process of converting hydrogen into helium – will cease, bringing an end to 10 billion years of stability. Indeed, as the Sun's core collapses, helium will fuse into carbon and the Sun will bloat up into a red giant, 256 times its original size. "The Sun will swell out to beyond the orbit of the Earth," says Dr Christopher McKay, a planetary scientist at NASA Ames Research Centre. The effects of all of this will be devastating for both the Earth and the entire inner Solar System and, at this stage, staying put on our planet will not be an option.

After all, the outer layers of the Sun will now be at escape velocity and peeling away. Mercury and Venus will be engulfed, and the orbits of the planets will be widening due to a weakened gravitational pull. "Even if it survives, the Earth will be inside the Sun's atmosphere," Dr McKay adds. And if all of this sounds quite gloomy for the future of mankind, then be assured that it is. "The issue for humans would be to survive to this time," says Dr Charnay, strongly hinting that there is every chance that nobody will be around to see any of it.

But let us suppose that humans do manage to get that far. Where will they be able to go when the Sun has turned a vivid red? Well, the smart money is on a lovely home overlooking Saturn and its stunning system of rings. For in the new order of the Solar System, Titan, one of Saturn's moons, is likely to become the number one destination for humans. It won't be easy – the journey to Titan from Earth takes some seven years, which will excessively burden the body and mind of any astronaut – but it could be the perfect escape route that will keep mankind going for many more millions of years. It may be hard to imagine that a moon which is ten-

CLIMATE SCIENTIST

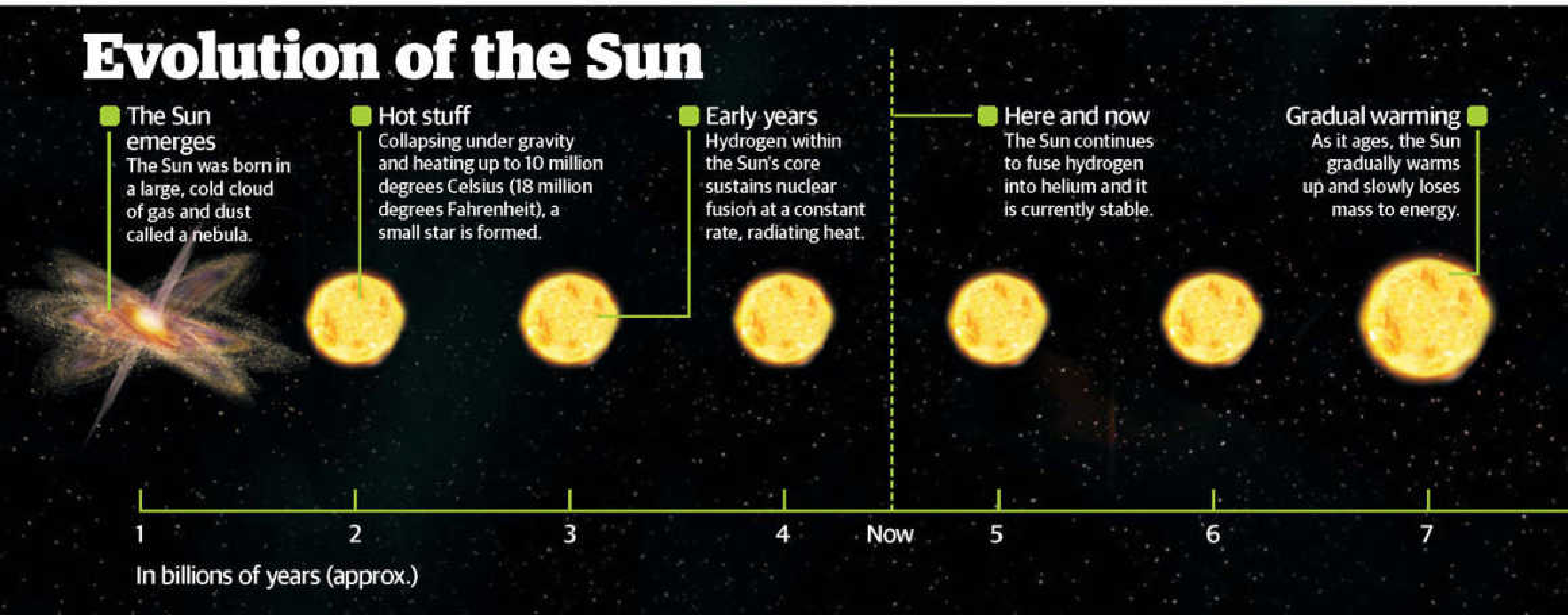
Benjamin Charnay

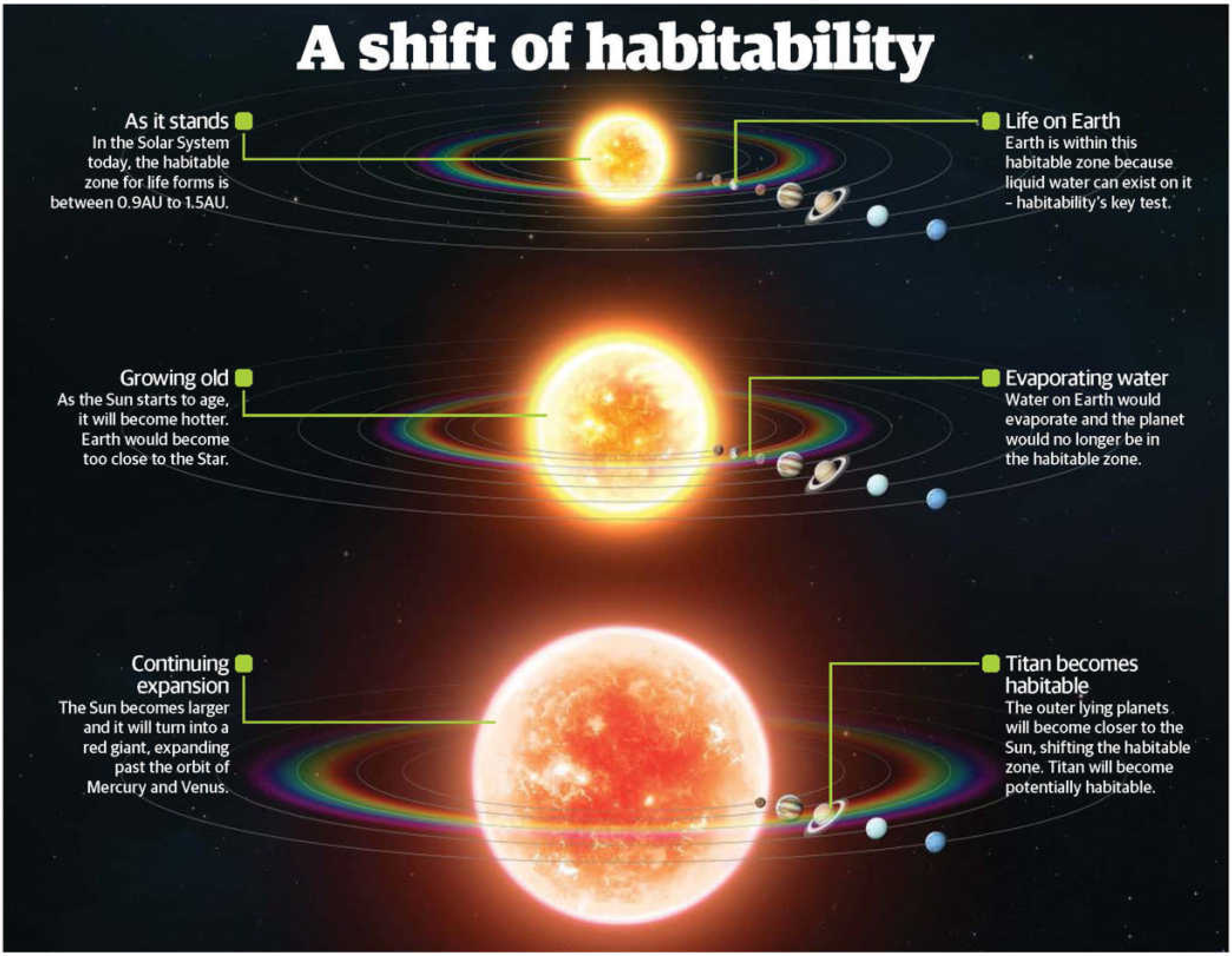
Virtual Planetary Laboratory

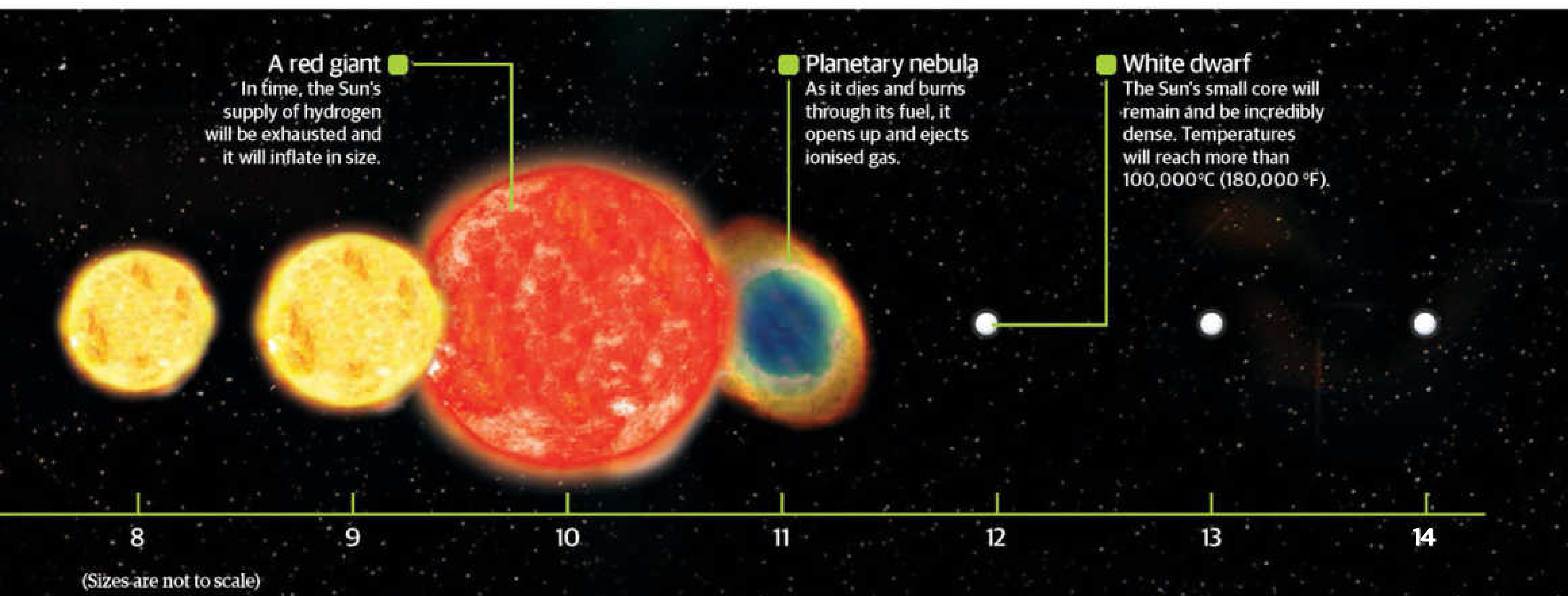
A postdoctoral scientist, Charnay is studying the planetary atmospheres and climates of Titan, exoplanets and the early Earth.

> "In around a billion years time, the Earth will probably no longer be habitable for humans" **Dr Benjamin Charnay, Virtual Planetary Laboratory**

Evolution of the Sun




A shift of habitability
As it stands
In the Solar System today, the habitable zone for life forms is between 0.9AU to 1.5AU.
Life on Earth
Earth is within this habitable zone because liquid water can exist on it – habitability's key test.
Growing old
As the Sun starts to age, it will become hotter. Earth would become too close to the Star.
Evaporating water
Water on Earth would evaporate and the planet would no longer be in the habitable zone.
Continuing expansion
The Sun becomes larger and it will turn into a red giant, expanding past the orbit of Mercury and Venus.
Titan becomes habitable
The outer lying planets will become closer to the Sun, shifting the habitable zone. Titan will become potentially habitable.


A red giant
In time, the Sun's supply of hydrogen will be exhausted and it will inflate in size.
Planetary nebula
As it dies and burns through its fuel, it opens up and ejects ionised gas.
White dwarf
The Sun's small core will remain and be incredibly dense. Temperatures will reach more than 100,000°C (180,000 °F).
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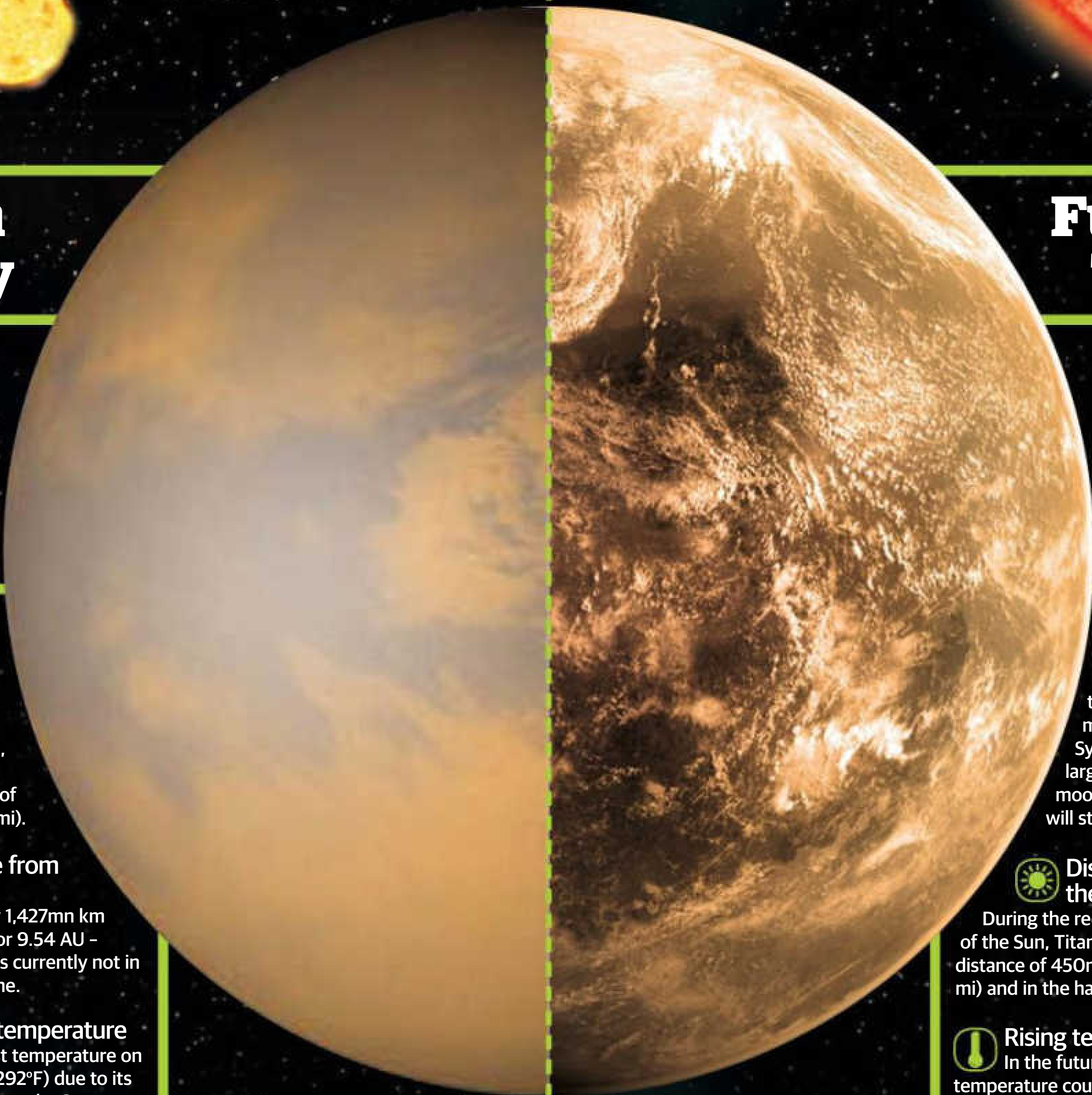
(Sizes are not to scale)

A potential home

When the habitable zone shifts, Titan could be our first destination



Titan today

What is it?
Titan orbits is the second largest moon in the Solar System, it orbits Saturn and has a radius of 2,576km (1,600mi).

Distance from the Sun
Titan is currently 1,427mn km (886.6mn mi) – or 9.54 AU – from the Sun. It is currently not in the habitable zone.

Current temperature
The highest temperature on Titan is -180°C (-292°F) due to its sheer distance from the Sun.

Titan's ice
Titan's mantle is composed of water ice and it is likely to harbour a layer of liquid water.

Liquid hydrocarbons
NASA says there are hundreds more liquid hydrocarbons on Titan than all the known oil and natural gas reserves on Earth.

Gravity and atmosphere
Titan has low gravity and a thick nitrogen atmosphere that is 1,000km (621mi) – ten-times larger than Earth's atmosphere.

Future Titan

What is it?
Titan will remain the second largest moon in the Solar System, as the largest – Jupiter's moon, Ganymede – will still exist.

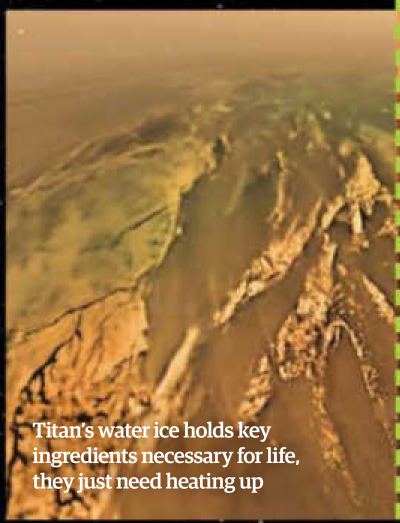
Distance from the Sun
During the red giant phase of the Sun, Titan will be at a distance of 450mn km (280mn mi) and in the habitable zone.

Rising temperatures
In the future, Titan's surface temperature could dramatically rise to -70°C (-94°F), which will allow some ices to melt.

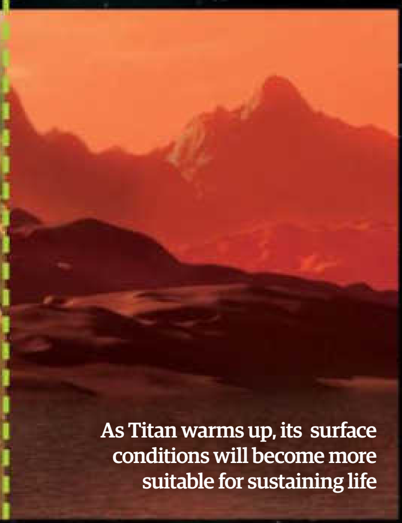
Flowing water
With a hotter climate and melted ice, Titan would host large oceans of life-giving water.

Organics will emerge
It will be a race against time in some respects, but Titan will have 100 million years for organics to heat and flourish.

Lovely atmosphere?
The upper atmospheric haze will deplete and important methane-based greenhouse effects will kick in.



Titan's water ice holds key ingredients necessary for life, they just need heating up



As Titan warms up, its surface conditions will become more suitable for sustaining life

times further away from the Sun than Earth could possibly be a new human base, but Titan is actually a close match for our planet. In many ways it mimics Earth's primitive state and it is almost waiting to be awoken so that it can unleash its potential. As such, it has proved fascinating for astronomers who have been building up data about the moon since Huygens, an atmospheric entry probe, landed there in 2005 following a seven-year journey as part of the Cassini-Huygens mission. It was the first ever landing accomplished in the outer Solar System and it will not be the last by any means. Come the day when space agencies are seeking to send manned flights to Titan, you can be assured that the technology needed to safely transport people 3.2 billion kilometres (two billion miles) across the Solar System will be very much in place.

Titan is actually one of only three worlds in the Solar System with surfaces and thick atmospheres – Venus and Earth being the others ("The thick atmosphere cuts down on radiation, so it is a very neutral environment," says Dr Mike Malaska, an expert of The Planetary Society, with a PhD in organic chemistry). It has a gravity that is similar to that of our own natural orbital satellite, making Titan the easiest place to fly and land in the Solar System – something that should help with future colonisation. Astronauts will be able to navigate Titan wearing just warm coats, as it benefits from having zero-to-low pressure unlike our Moon or Mars. "The Moon and Mars both share the problem that if humans didn't wear spacesuits they would die rapidly from depressurisation, which the movies like to show as being explosive," says Dr McKay. "On Titan a spacesuit is not required."

Titan has weather and it is the only body in the Solar System other than Earth to possess surface lakes and seas. It also has river channels, dunes and complex hydrocarbons, along with pebbles of ice that point to an existence of water in the past. Crucially, it has copious organic raw materials. "These would be great for colonialists to use for manufacturing things," adds Dr Malaska. "The diversity of features on the surface suggests that there might be different patches of different types of organics – kind of like the different rock outcrops here on Earth. There might also be outcrops of water ice, so water might be available after heating it high enough to melt it."

Indeed, astronomers say that all Titan effectively needs is warming up to make it a viable home. "Temperature is a current problem on Titan," says Dr McKay, as the moon receives one hundredth of the solar heat we get here on Earth. "At -180 degrees Celsius (-292 degrees Fahrenheit), if you visited today, it would feel like plunging into freezing cold water, so humans would have to find a way of keeping very warm. We'd have to wear special spacesuits like the ones divers wear. Yet all this changes once the Sun becomes a red giant."

When the Sun does change, Titan will be smack bang in the midst of a new habitable zone, which will have moved deeper into the Solar System, stretching from 49.4 AU to 71.4 AU, taking it as far as the Kuiper Belt. The frozen moons of the outer planets will become far warmer, melting ice into liquid water and allowing life a chance to flourish. As Dr McKay, Ralph Lorenz and Jonathan Lunine wrote in an important

"The Sun will swell out to beyond the orbit of the Earth. So, even if the Earth survives this it will be inside the Sun's atmosphere" **Dr Chris McKay, NASA**

This radar image, taken by the Cassini spacecraft, shows empty and liquid-filled depressions on Titan

A close-up radar image of Ligeia Mare, the second largest known body of liquid hydrocarbons on Titan

PLANETARY SCIENTIST

Dr Chris McKay
NASA

McKay is interested in the evolution of the Solar System. He is also involved in the planning of future human exploration missions to Mars.

paper published in 1997, Titan would respond well to being given a new lease of life and humans could benefit greatly from it.

Quite apart from the Sun raising the moon's temperature to -70 degrees Celsius (-94 degrees Fahrenheit), they noted that the surrounding thick orange haze of Titan's atmosphere would also be depleted. Since the haze currently allows the surface to be unaffected by the increase of solar radiation caused by the Sun being closer and hotter, this would enable a greenhouse effect, creating an environment that would be suitable for life. Things would begin to slot into place.

What's more, the warmer moon would also change the composition of the atmosphere. Currently it is made up of 98 per cent nitrogen (compared to 80 per cent on Earth) and two per cent methane and "the air is thicker than Earth by a factor of seven," says Dr McKay. But five billion years from now, "the luminosity will be large enough to affect the icy crust and liberate a water-ammonium ocean," says Dr Charnay. The effects will be jaw-dropping.

Dr Carrie Anderson, the associate chief at NASA's Planetary System Laboratory, says the water will melt, mix with the organics and make up amino acids, which contain carbon, nitrogen, oxygen and hydrogen – the basic elements necessary for life. "Titan has all of these," she told an audience at the Library of Congress in the US. "It's just waiting. It's ready to go."

Even so, there are doubts: "It would be difficult to produce an oxygen-rich atmosphere because Titan's atmosphere and interior are very reducing," says Dr Charnay. "For instance, there is a lot of methane which would react to destroy oxygen." There would also be something of a race against time in order for life to form and flourish. Titan will have a window of "just" 100 million years for life to emerge, for reasons we'll come to in a moment. Dr Anderson believes this is sufficient time for life to form on Titan, though, making it a viable future home for humans.

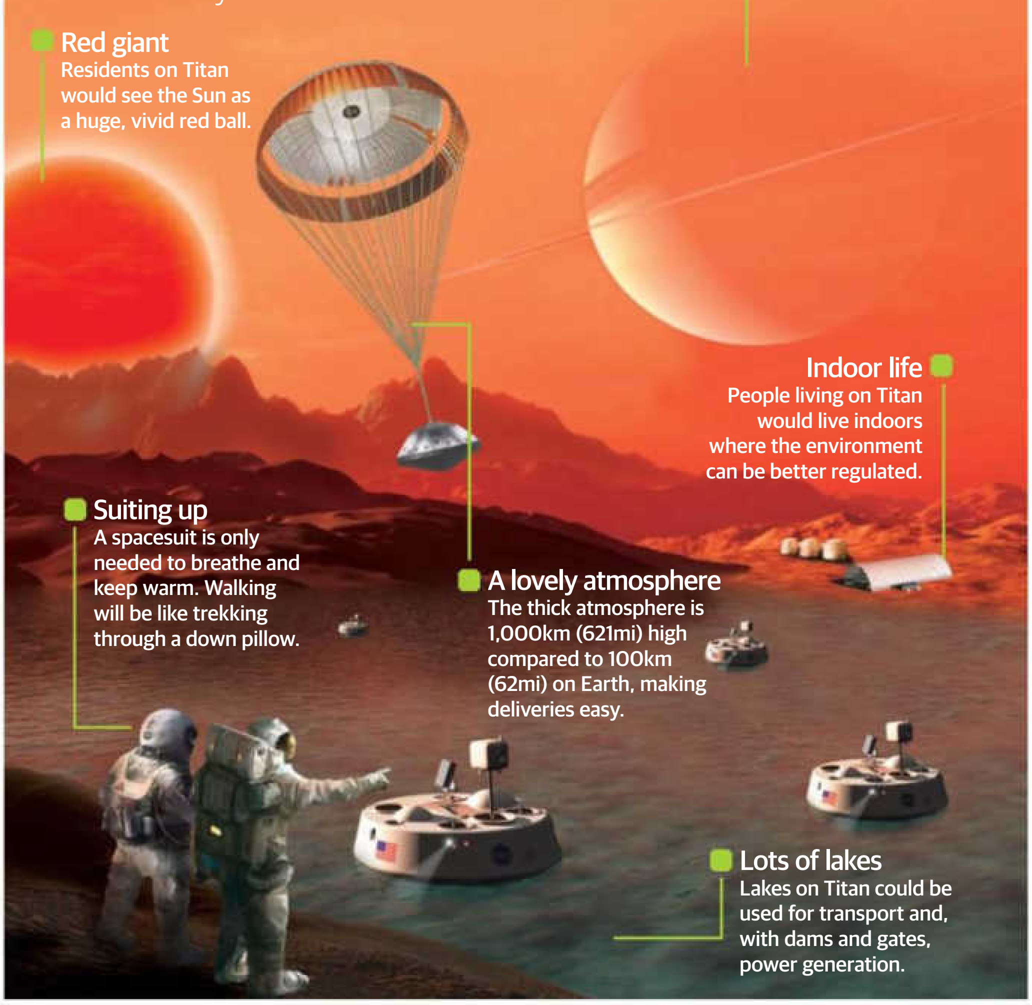
"Remember, at this moment in time the ice will melt in the mantle, and a lot of it should melt, so you should have liquid water. Then we have all those organics just sitting around on the surface just waiting for the Sun to heat them up," she says. It is a prospect that also excites Dr Malaska.

"When the Sun evolves into a red giant, Titan will heat up," says Dr Malaska. "The water ice in the crust will melt, and the organics on the surface will probably react with water, each other, and themselves. It'll be a wonderfully interesting organic

> "Discovering life on Titan would change our understanding of the fundamental processes of biology" **Dr Mike Malaska, Planetary Society**

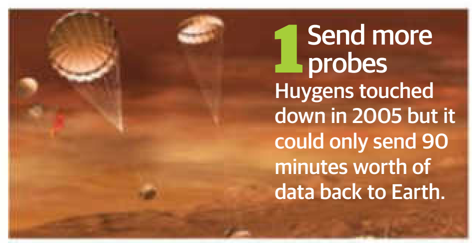
Setting up home around Saturn

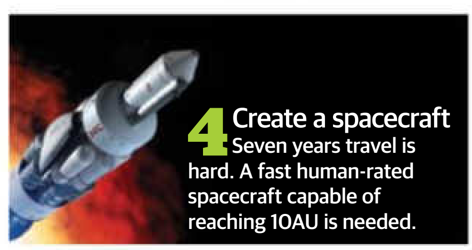
It may have similarities with Earth but what would it really be like to live on Titan?



How to get to Titan

It's good to be prepared





chemistry mess. Most of the organic 'goo' will be floating on the surface of the water."

And yet there is a possibility that life already exists on Titan. Dr Malaska says life could be based on different sets of molecules and interactions, and that microscopic alien organisms may be swimming in seas of methane. Could this have a profound effect on our ability to colonise Titan in the event of a red giant? Would questions be raised over our chances of adapting and living alongside such alien life? Time will tell, and scientists will be working on those very answers. "If we discover life on Titan, it would be incredibly huge," says Dr Malaska. "It would be a fundamentally different type of life and would take our fundamental understanding of biological processes to a new level."

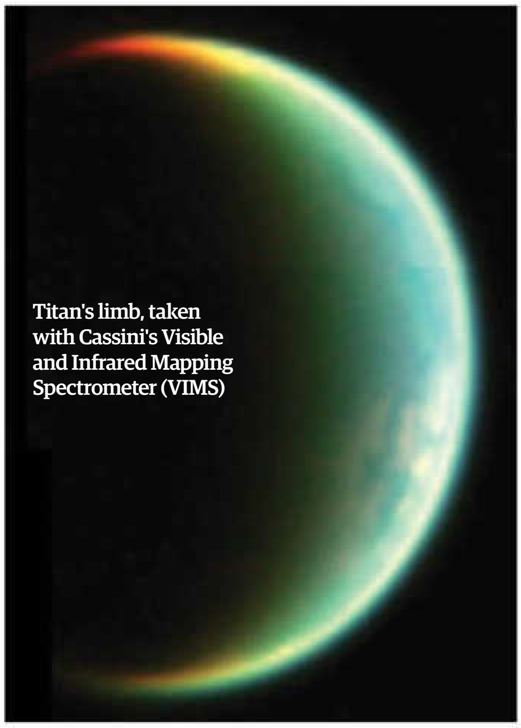
He claims that Titan has already changed how we think about geology: "Comparing and contrasting the geology of Earth and Titan is a powerful tool. With regards to geology, we now talk about how lakes and rivers work, and now have examples using both water and hydrocarbons, so we can understand the fundamental processes even though the materials, temperatures and gravity fields are totally different.

"Discovering life on Titan would likewise change our understanding of the fundamental processes of biology. It would extend our concept of the habitable zone where surface liquids exist to a different temperature range and set of surface conditions. It would also tell us that there may be even wilder and weirder temperature and chemical regimes that we can start to think about."

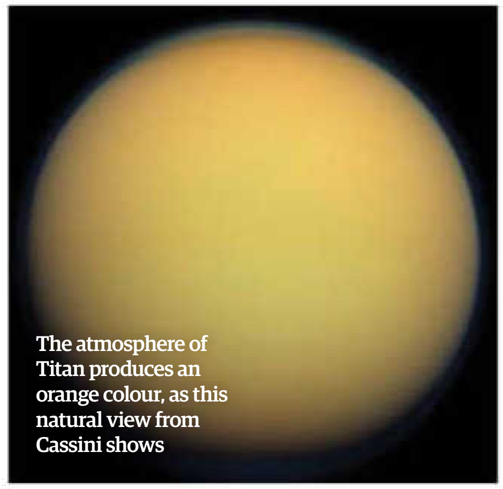
But even if life exists, emerges or travels to Titan, one thing is certain: it won't be staying there forever. Any migration from Earth to Titan will always be temporary since it will start to get too close to the Sun. Once those 100 million years are up, liquid water on Titan will evaporate and the moon will suffer an incredible rise in heat. But there is a potential for a reprieve. The Sun will later contract and become a white dwarf that will burn for a billion years. This will place Titan back into the habitable zone once again. It means any humans who escape to Titan and then suffer another setback – as Titan is burned dry – could, if they somehow hold out (and quite how is anybody's guess), have another opportunity for a long existence on Saturn's moon. As Dr Anderson told her audience: "Maybe life has a real chance on Titan during those one billion years." For the sake of the future of humanity, we sincerely hope it does.

"Titan has all of the basic elements necessary for life just sitting around on the surface just waiting for the Sun to heat them up"

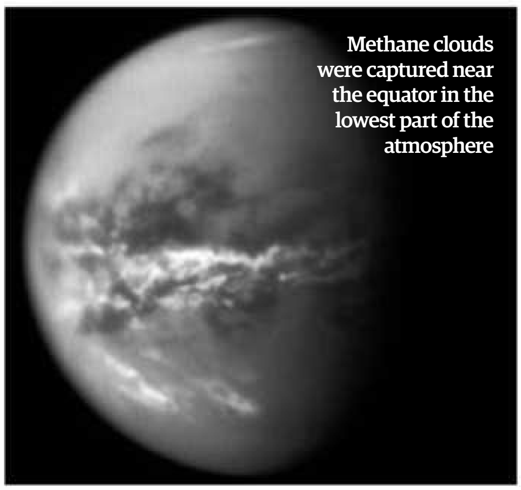
Dr Carrie Anderson, NASA



Titan's limb, taken with Cassini's Visible and Infrared Mapping Spectrometer (VIMS)



The atmosphere of Titan produces an orange colour, as this natural view from Cassini shows



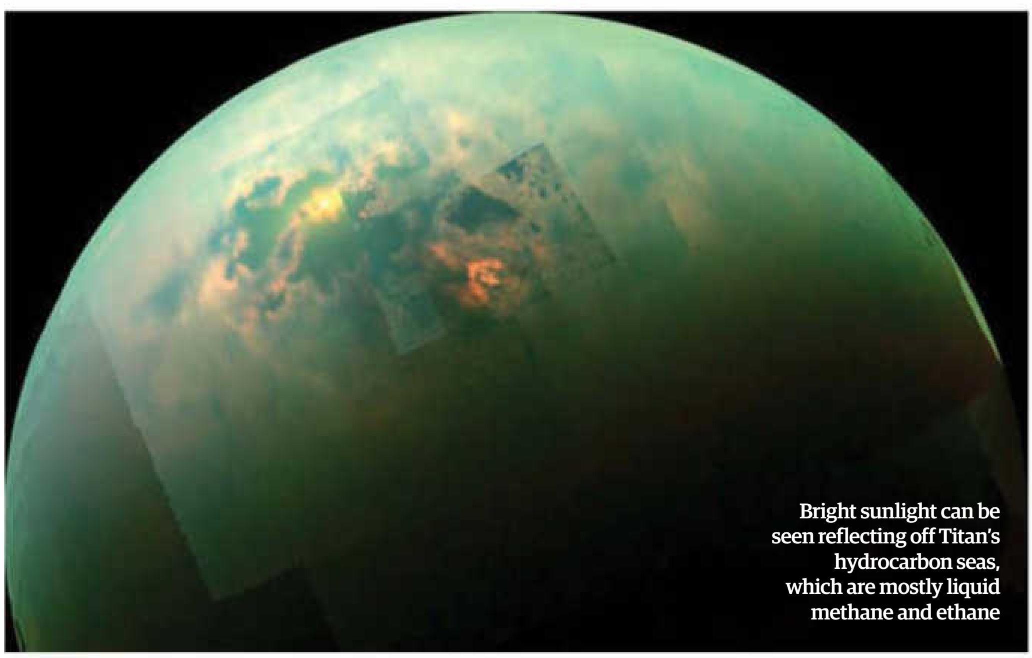
Methane clouds were captured near the equator in the lowest part of the atmosphere

PLANETARY EXPERT

Dr Carrie Anderson

NASA

Associate chief at NASA's Planetary Systems Laboratory, Dr Anderson's research investigates the similarities between Titan's current state and Earth's early conditions.



Bright sunlight can be seen reflecting off Titan's hydrocarbon seas, which are mostly liquid methane and ethane

Exploring Io

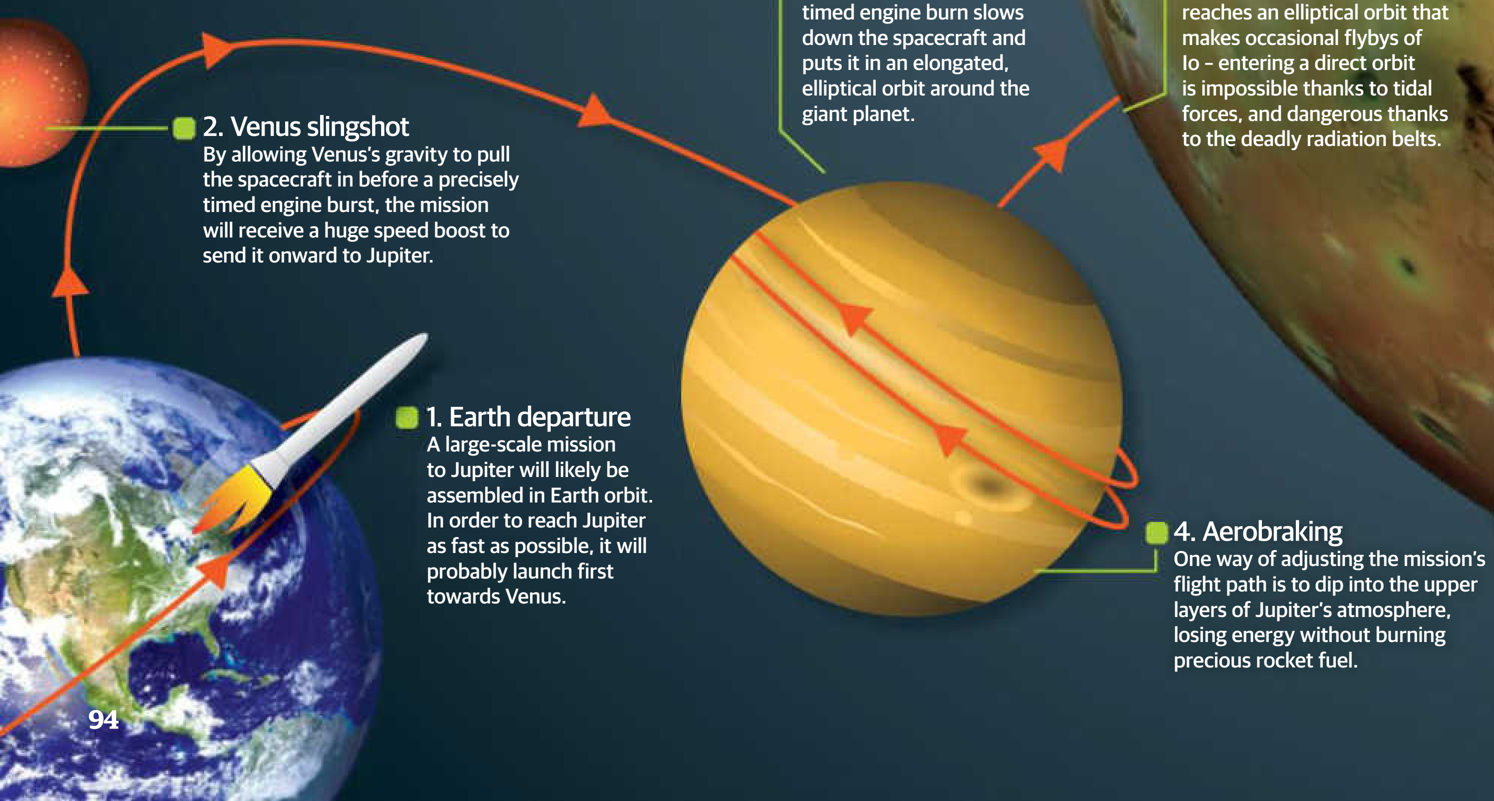
The most dangerous moon in our Solar System, a tortured world wracked with volcanoes and bombarded with radiation from nearby Jupiter

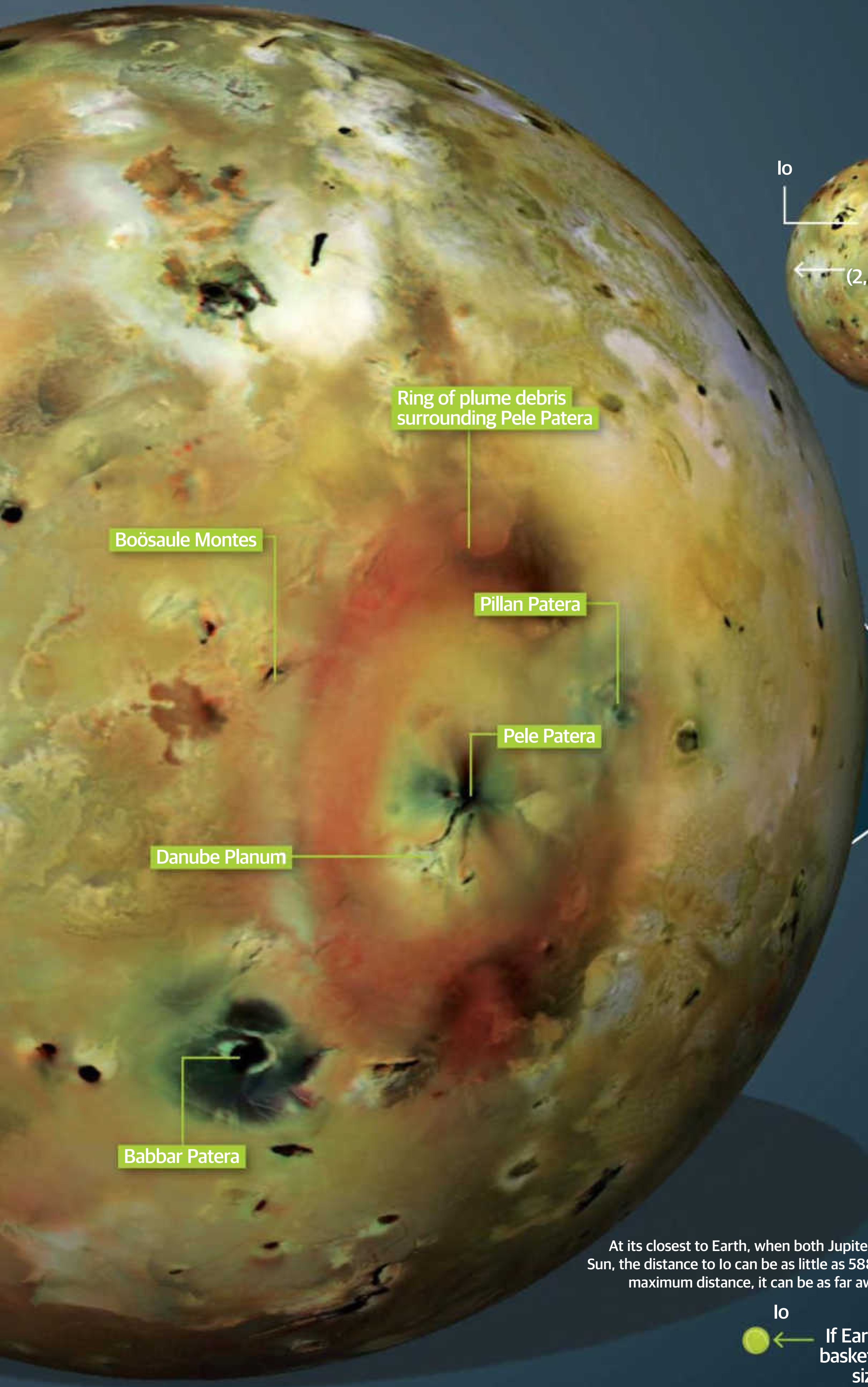
Io is the fifth closest satellite of the giant planet Jupiter, and the innermost of the four major 'Galilean' moons – worlds so large they might be considered planets in their own right if they weren't trapped in orbit around the largest planet in our Solar System. Orbiting Jupiter in just 42 hours, Io is slightly bigger than our own Moon, but hugely different in many other ways. While our satellite has been geologically dead for more than 3 billion years, Io is home to violently active volcanism – huge plumes of erupted material arc high into its almost-airless skies before falling down to blanket the landscape, while volcanic fissures ooze sulphurous lava onto the surface, re-shaping it at a rate unseen on any other world.

All this activity is driven by powerful tidal forces – as Io circles Jupiter, its distance from the giant planet varies by about 3,000 kilometres (1,865 miles), therefore the strength of Jupiter's gravity also changes. This pushes and pulls the moon's interior in different directions, causing rocks to grind past each other, generating huge amounts of heat to warm the interior. If Io were Jupiter's only major moon, then these tidal forces would have manipulated its orbit into a perfect circle long ago, but the repeated outward tug from its outer neighbours, Europa and Ganymede, prevents this from happening and ensures Io has no escape from heating.

Another factor affecting Io's volcanism is the large amount of easily-melted sulphur in its crust. On Earth, volcanoes involve silicate rocks that melt at temperatures around 900 degrees Celsius (1,652 degrees Fahrenheit), and while Io does have some hot spots where this kind of activity occurs, most of the lava that oozes across its surface or erupts in its plumes consists of sulphur compounds that melt at far lower temperatures. Io's colourful, hellish landscape largely arises because sulphur and its compounds have a natural tendency to take on forms or 'allotropes' with varied colours and structures.

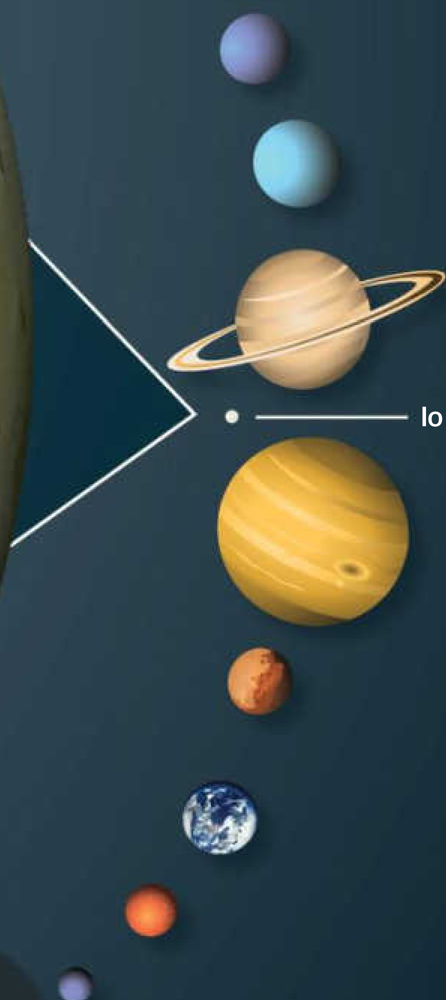
How to get there





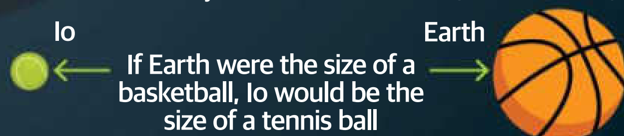
How big is Io?

Io's diameter of 3,642 kilometres (2,263 miles) is some 168 kilometres (104 miles) larger than the size of Earth's own Moon.



How far is Io?

At its closest to Earth, when both Jupiter and our own planet are on the same side of the Sun, the distance to Io can be as little as 588 million kilometres (365 million miles). But at its maximum distance, it can be as far away as 968 million kilometres (601 million miles).



Top sights to see on Io

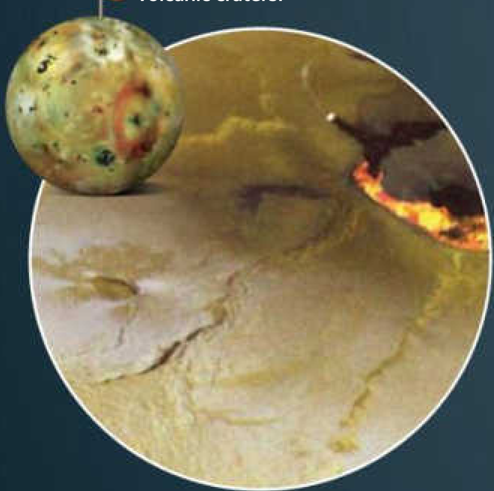
Io's volcanic activity is powerful and frequent enough that the moon's landscape is redrawn every few decades – each space probe that has flown past since the 1970s has found it looking significantly different. The longest-surviving features identified are Pele and Loki, each of which is a volcanic caldera with complex cracks in the crust, a lava lake of molten rock, and occasional 'plume' eruptions.

Loki is a 200-kilometre (124-mile) depression whose fragile crust periodically collapses only to be resurfaced. Pele is a smaller caldera at about 30x20 kilometres (19x12 miles) across, but produces more frequent outbursts – one of its plumes was the first sign of volcanic activity to be discovered on Io by Voyager 1 in its 1979 flyby. Io's plume eruptions, some of which reach more than 300 kilometres (186 miles) into the sky, are thought to be driven by a process similar to Earth's geysers, as pressurised liquid sulphur boils off into the near-vacuum through weak points in the surface. As these compounds fall back to the ground and cool, their chemical structure rearranges, creating a red, bruise-like ring around the caldera. Some of the plume material escapes into space, where it is swept up by Jupiter's magnetic field, forming a doughnut-shaped ring or 'torus' surrounding Io's orbit.

In stark contrast to volcanoes found on the Solar System's inner planets, the lava of Io's volcanoes spreads out rapidly across the terrain, and does not build up a cone around the volcanic fissure.

Despite this, however, Io's terrain is far from flat. It features large, isolated mountains with an average height of around six kilometres (3.7 miles) – so tall that they must be composed of strong silicate rocks rather than weak sulphurous ones. These mountains are thought to be chunks of Io's deep crust, forced upwards by thrust-faulting – a collision between chunks of crust driven in opposite directions by currents in the underlying mantle, pushing one mass of rock over the other. The tallest mountains, known as Boösaule Montes, lie just south of Io's equator and tower more than 17.5 kilometres (10.9 miles) above the lava plains – they have a multilayered appearance, as layers of solidified lava from countless sulphur eruptions have built up on the underlying rock.

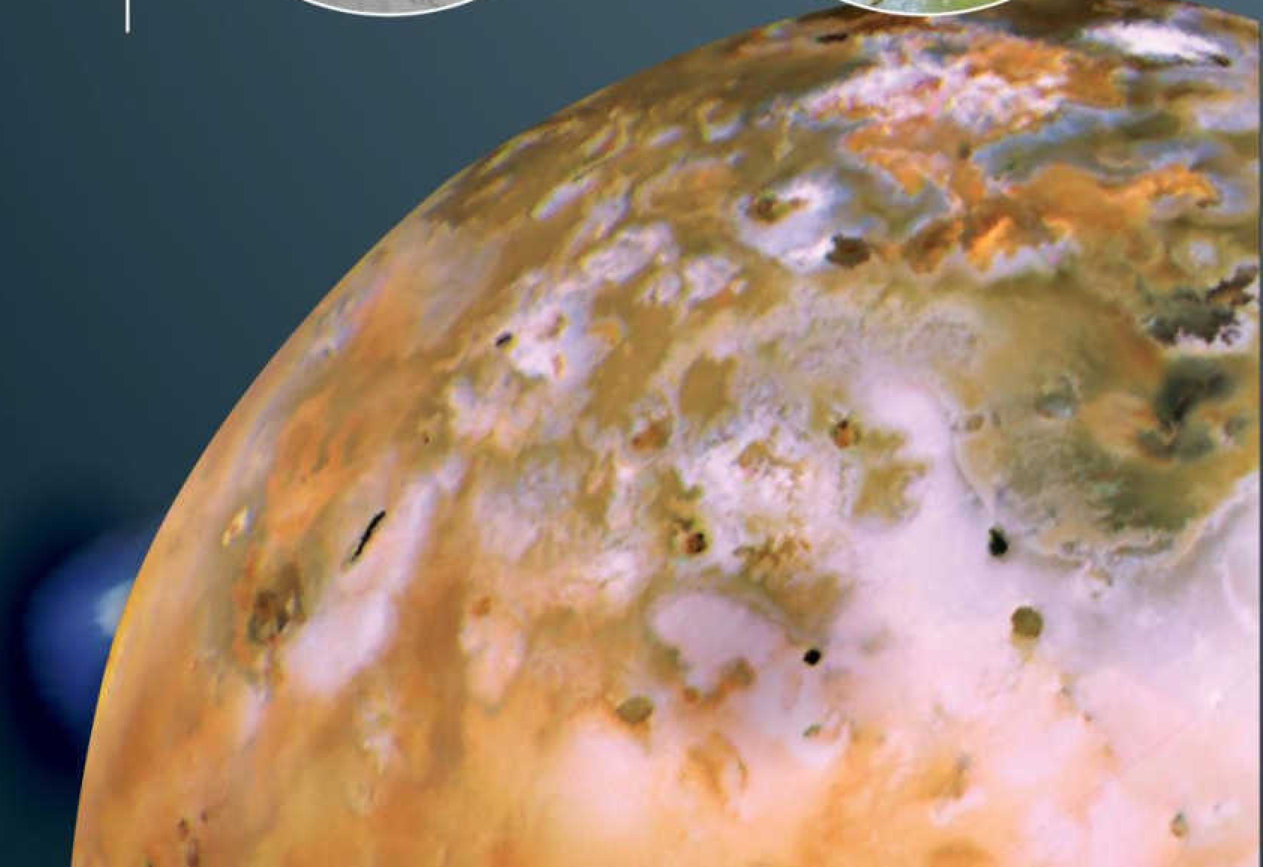
Tvashtar Catena
Exposed lava on Io's surface usually solidifies rapidly, so NASA's Galileo probe struck it lucky when it photographed this glowing lava fountain in a chain of volcanic craters.



Tohil Mons
This 5.4-kilometre (3.4-mile) mountain is thought to have formed from a complex mix of processes, including volcanic eruptions, the erosion of earlier mountains and subsequent further deformation.

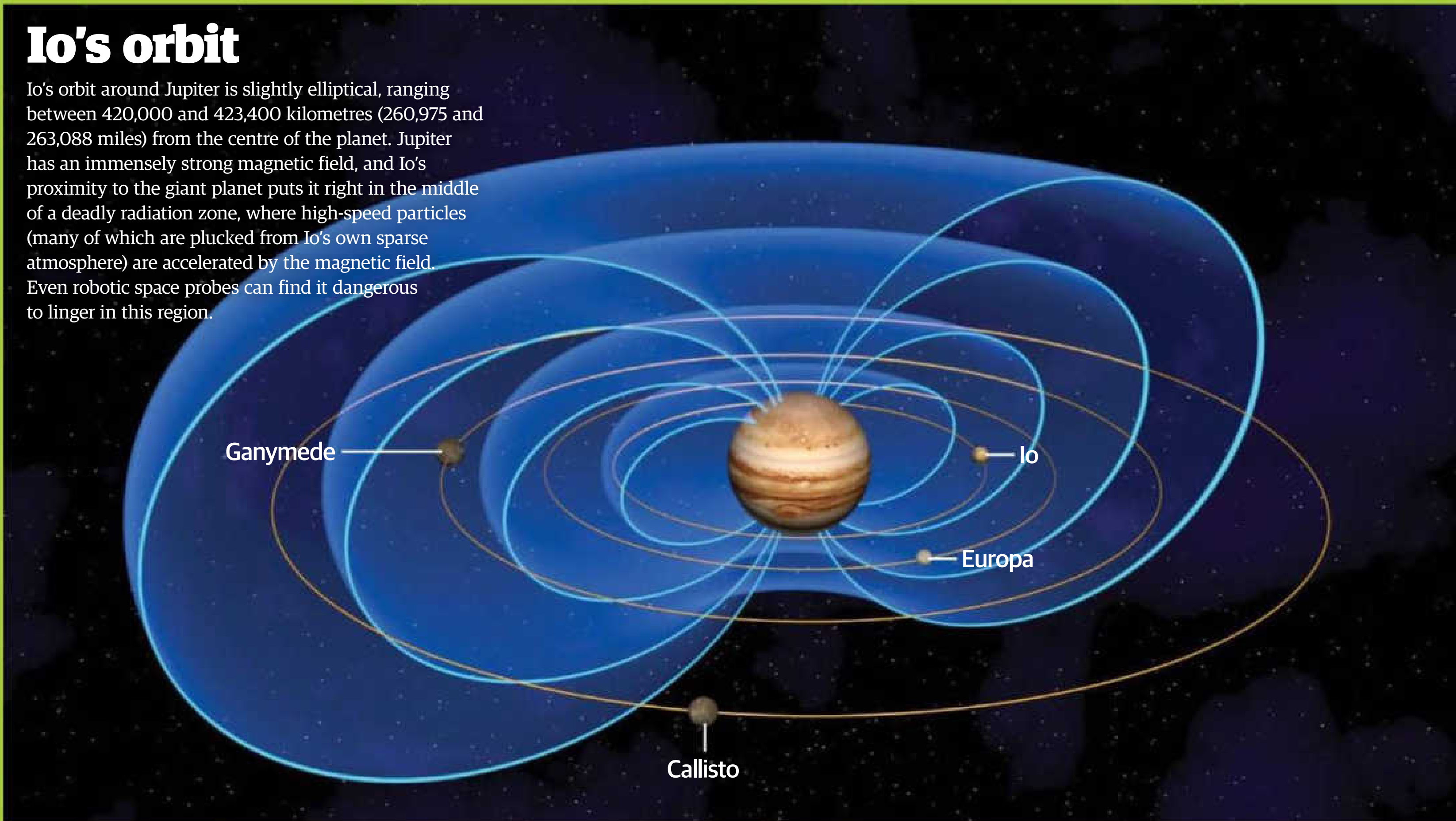
Pillan Patera
Taken five months apart, these photos show how fast Io's surface changes – the dark patch at the top right, created by an erupting plume from the small central volcano, is 400 kilometres (249 miles) in diameter.

Loki Patera
This plume erupting above Loki was one of the first volcanic features found on Io, just weeks after the first predictions of an active moon were published in 1979.



Io's orbit

Io's orbit around Jupiter is slightly elliptical, ranging between 420,000 and 423,400 kilometres (260,975 and 263,088 miles) from the centre of the planet. Jupiter has an immensely strong magnetic field, and Io's proximity to the giant planet puts it right in the middle of a deadly radiation zone, where high-speed particles (many of which are plucked from Io's own sparse atmosphere) are accelerated by the magnetic field. Even robotic space probes can find it dangerous to linger in this region.



Io in numbers

5 *Io's position in the Jovian system as four smaller moons orbit even closer to Jupiter*

Weather forecast

-160°C (-256°F)

Temperatures on Io can vary from extremely hot to extremely cold. In areas of volcanic activity, temperatures can reach 2,200°C (4,000°F), but away from these areas, temperatures can plunge to -160°C (-256°F). Since most of the atmosphere comes from its volcanoes, the air of Io is primarily made of sulphur. However, Io does not have any clouds as it has no magnetic field, which means its atmosphere is continually lost to space.

0.183g *Io's surface gravity in comparison to Earth's*

0.015 *Io's mass in terms of Earth's*

90% Proportion of sulphur dioxide in Io's tenuous atmosphere

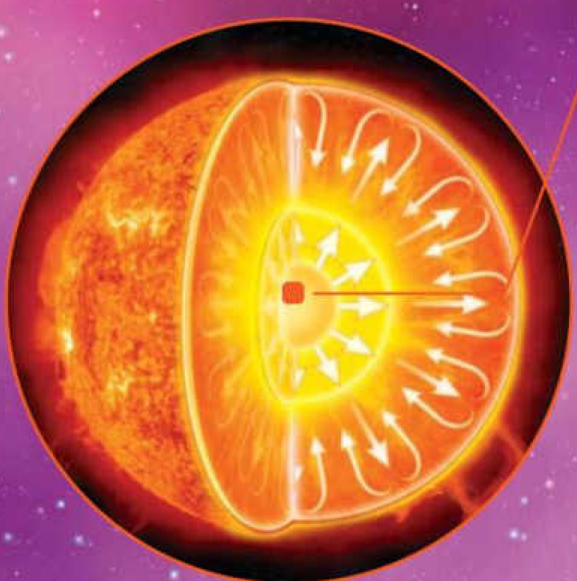
-160°C *Io's average surface temperature, which varies by about 20°C (36°F) either way*

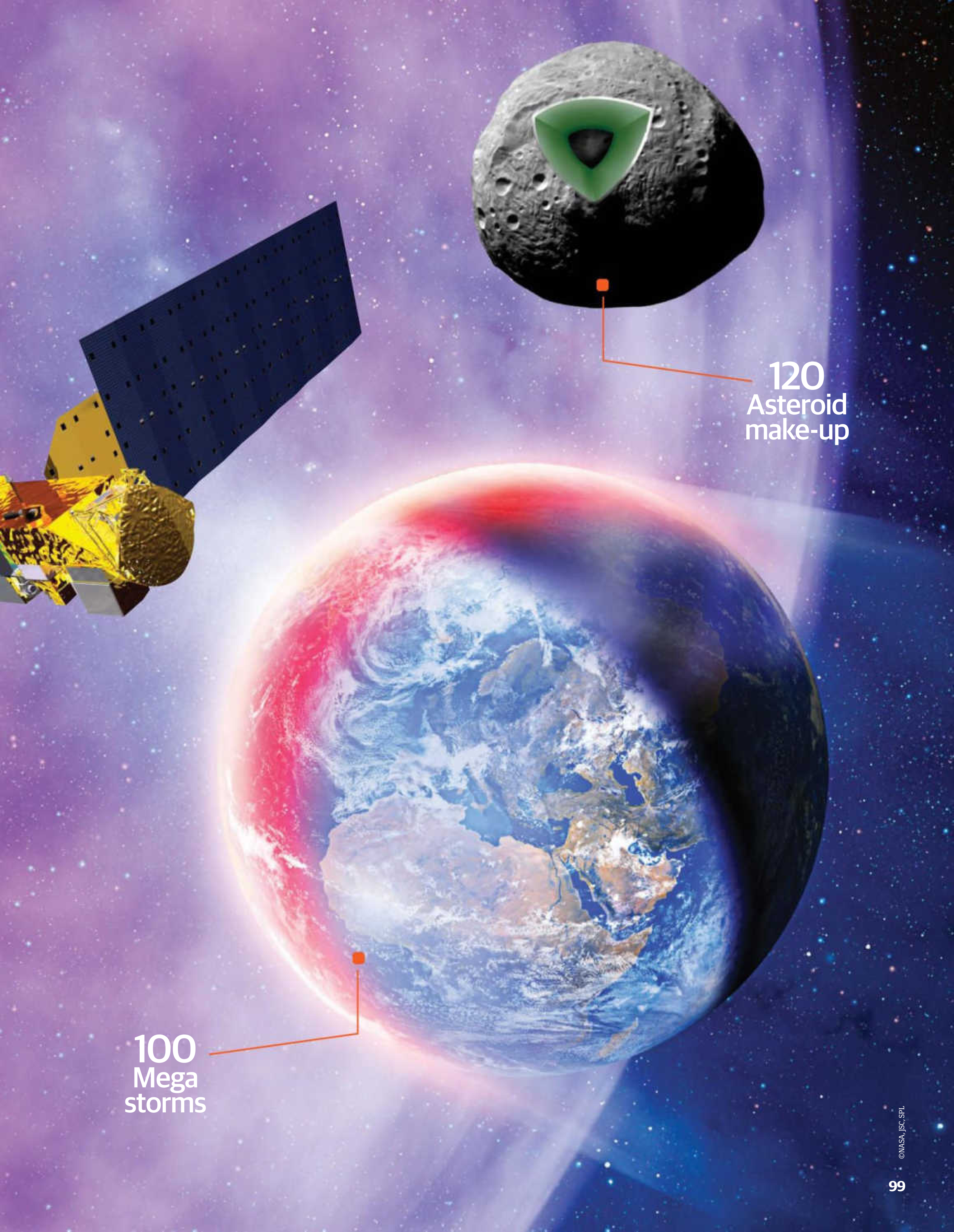
0.286 Io's radius in comparison to Earth's

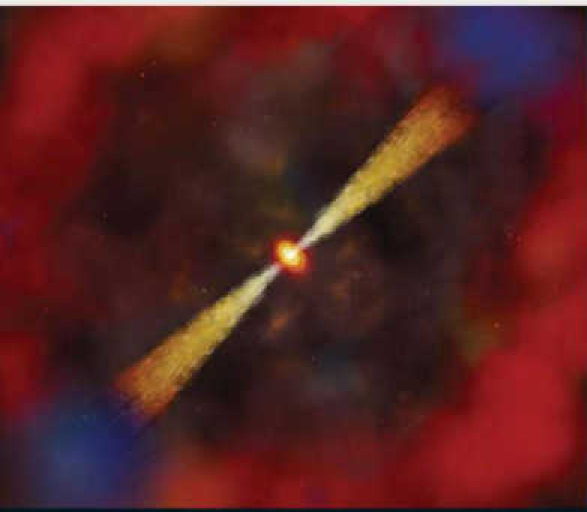
Io's orbital period around Jupiter and the time taken to spin on its axis

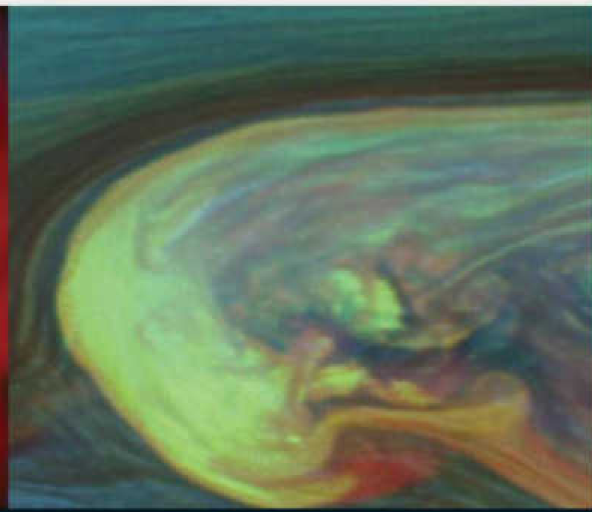
Sights of the universe

From what stars are made of to our relationship with space



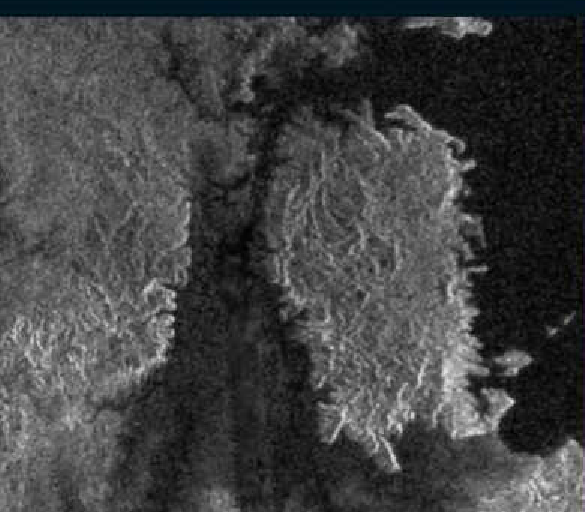

120
Asteroid
make-up
100
Mega
storms





DEADLY WEATHER IN SPACE MEGA STORMS

From solar flares that knock out satellites to 1,500mph hurricanes on the surface of alien worlds, we explore some of the most extreme weather in the Solar System



Our angry, stormy Sun

We know our Sun as a brilliantly bright sphere that rises in the east and sets in the west each day. That's a simple way to describe it; what really goes on on its surface is far from the impression that it gives as it hangs, almost calmly, in the daytime sky.

While going anywhere near the Sun would be suicide with the searing heat and penetrating radiation combining to fry you alive in your spacesuit, technology has revealed this star to be an angry, bubbling cauldron of solar activity.

First up are solar flares - bursts of radiation from the sudden release of magnetic energy from active regions on the Sun's surface, the photosphere. These regions are centred on sunspots, which are tangled knots of magnetic fields. The flares release as much as a sixth of the total amount of energy that the Sun releases every second, with much of it in X-rays or ultraviolet light. The energy of a flare can drive a cloud of charged particles to escape the solar corona in a coronal mass ejection (CME). The CME becomes a giant cloud of plasma hurtling through space and, when CMEs are pointed towards Earth, they cause solar storms.

When a CME strikes the Earth's magnetosphere, it overloads the system and becomes a geomagnetic storm. Earth's magnetosphere is compressed to breaking point with charged particles flooding the magnetic field lines that loop down on to the magnetic poles of the planet. The particles excite atmospheric gases (mainly oxygen and nitrogen), causing them to glow in eerie shimmering curtains of light – the aurora borealis (northern lights) and the aurora australis (southern lights). Oxygen gas glows green, while nitrogen glows purplish-red - the two primary colours seen in auroras. Usually low-level solar wind activity means that the 'auroral arc' is kept, in the northern hemisphere, to the Arctic Circle but the power of a geomagnetic storm can see the auroral arc extend to more southerly latitudes, over Britain and Western Europe, as far south as Spain or even, on very rare occasions, Florida in the United States. The most severe solar storm on record was the Carrington event of 1859, when auroras lit up the skies as far south as the tropics and telegraph wires began to short, sparking electricity.

Those telegraph wires remind us that auroras are only the pretty side of a geomagnetic storm. Although they are not directly harmful to people on the ground, a storm instigated by a powerful CME can destroy our technology. Satellites can short-circuit, knocking out communications. Astronauts must take shelter from the radiation in a special, shielded room onboard the International Space Station. On the ground, power lines can become swamped by raw current from the CME plasma - in 1989, a solar storm caused a large, nine-hour blackout in Quebec in Canada. In our modern world, where we rely on electronic devices, the nightmare scenario is that a powerful enough solar storm could stop everything working, wiping computers, crashing the internet, knocking out global

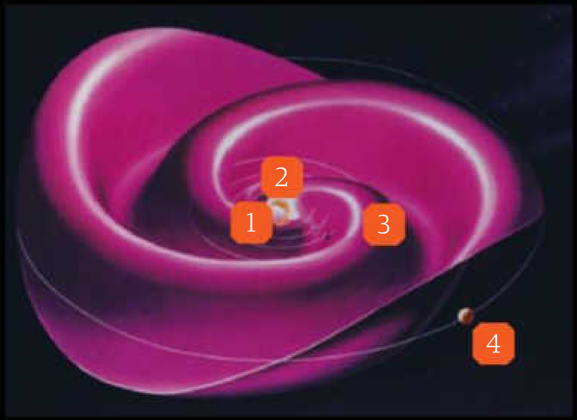
Solar wind current

1. Surface of the Sun
The Sun's magnetic field is very complex on the solar surface, but as it rises into the corona it simplifies until it consists of two opposite polarities separated by the line of the heliospheric current sheet.

2. Corona
In the corona the solar wind begins to draw out the heliospheric current sheet into space, extending the Sun's atmosphere out into the rest of the Solar System.

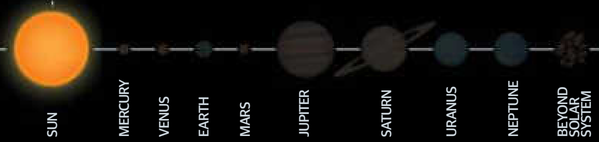
3. Rotation
As the Sun rotates, it causes the heliospheric current sheet to become twisted.

4. Jupiter
It takes material in the heliospheric current sheet three weeks to reach Jupiter. The sheet eventually extends out into the Kuiper belt, where the Voyager spacecraft are exploring.

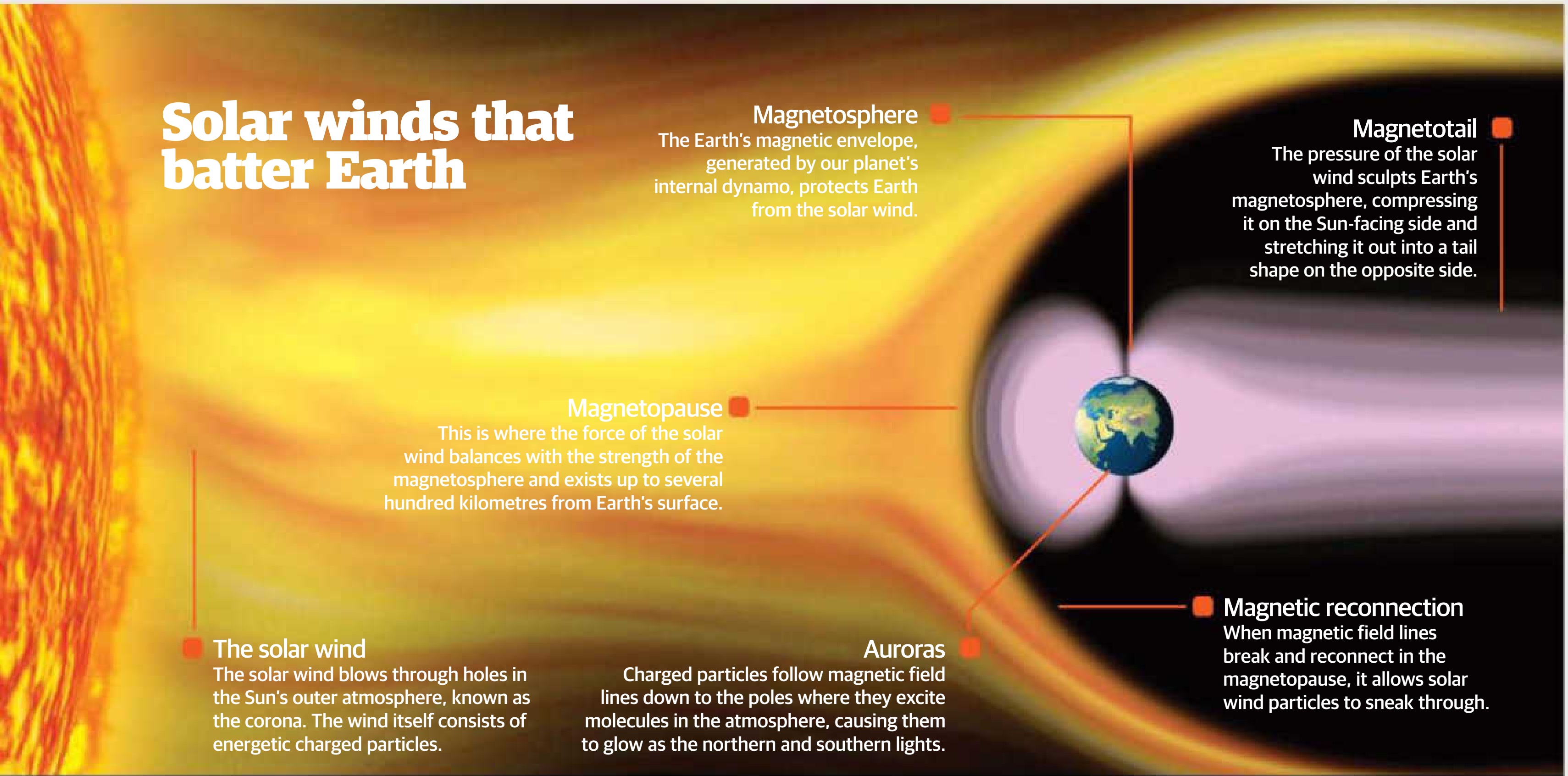


A solar prominence is an eruption of hydrogen gas from the Sun's surface

WHERE DOES THIS HAPPEN?



Solar winds that batter Earth



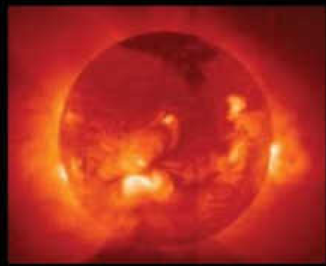
"A powerful enough solar storm could wipe computers, crash the internet and knock out global power systems"

power systems and disrupting communications. It may take months to get everything back online, in which time the world has been sent into technological, social and economic chaos.

We're most vulnerable to solar storms at solar maximum, which is the point in the Sun's 11-year cycle of activity when our nearest star is at its most active. Solar flares happen all the time, and CMEs strike Earth frequently, but only rarely are they as powerful as the solar activity that plunged Quebec into darkness. However, scientists are currently unable to predict solar activity or when the next big CME will be.

All of this takes place in the Sun's heliosphere, which is the extent of its magnetic influence throughout the Solar System, where the solar wind still blows. The heliosphere goes out past the orbit of Pluto. The Voyager 1 spacecraft is currently 118 times further from the Sun than Earth is, and yet it has still to leave the heliosphere. CMEs disperse and lose power the deeper they get into the Solar System. However, solar activity can still have an effect, even on the edge of the heliosphere. Both Voyager 1 and 2 have experienced the heliosphere swelling and shrinking on gusts of the solar wind that inflate the Solar System's magnetic bubble.

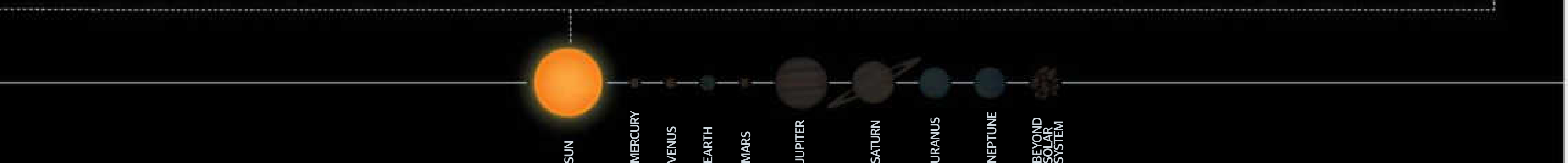

The aurora borealis (northern lights) and aurora australis (southern lights) can be seen in the northern and southern hemispheres of our planet



The solar maximum

Roughly every 11 years, the Sun goes through a natural cycle marked by an increase or decrease in dark blemishes on the Sun's surface, or photosphere, known as sunspots. We refer to the multiplication of sunspots as the solar maximum and the smaller number the solar minimum.

During the solar maximum things get exciting; bright luminous regions also appear in the Sun's atmosphere, called the corona, and it is here where our Sun has an angry outburst; fiercely spitting charged particles and magnetic fields from its surface in a gigantic burst of a supersonic solar wind, called a coronal mass ejection.

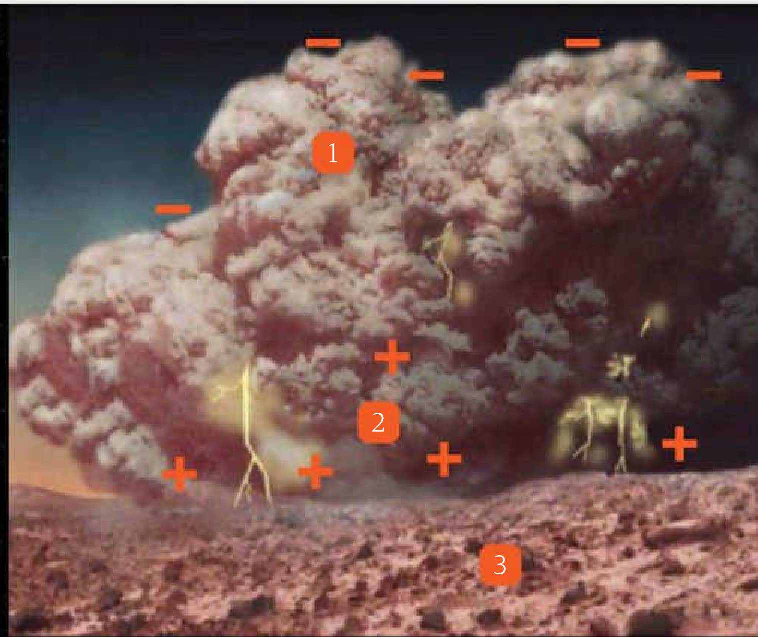


Dust storms that cover the planet

Now this is really bad weather – a dust storm that doesn't just cover an area, or even a hemisphere, but the entire planet. During summer in the Red Planet's southern hemisphere, when Mars is at its closest point to the Sun, solar heating can drive immense storms that blow up red dust and can obscure the surface for months. In 1971, when Mariner 9 arrived at Mars, it found the whole planet hidden under a veil of dust, with only the volcano Olympus Mons visible. More recently, the Mars Exploration Rovers Spirit and Opportunity would struggle to survive in dust storms as the Sun's light was blocked and their solar panels covered by a coating of dust.

On Earth, moisture arms swirling storms, but on Mars there is only dust. Normally most of the dust is on the ground, but some is found in the atmosphere, where it scatters sunlight and makes the sky appear pinky-red. When Mars is at its hottest – still cold enough to freeze water – the atmospheric dust can absorb the energy of the sunlight, which causes warm pockets of air to rapidly move towards colder, low-pressure regions, generating winds up to 45 metres per second (162 kilometres per hour or 100 miles per hour) that begin to pick up dust particles from the ground, adding to the atmospheric dust content and increasing heating, pushing the winds harder and faster until the atmosphere is filled by dust.

And then, just as quickly, the storm can die down. Perhaps by blocking the sunlight, the surface of Mars grows cooler, allowing some of the dust to begin sinking out of the atmosphere. Not all dust storms swallow the entire planet – some are more localised events. However, were you to be on the surface during a dust storm, other than the sky darkening and a fine coating of dust settling over you, the atmosphere is so thin that you'd barely notice the wind or the scouring dust.

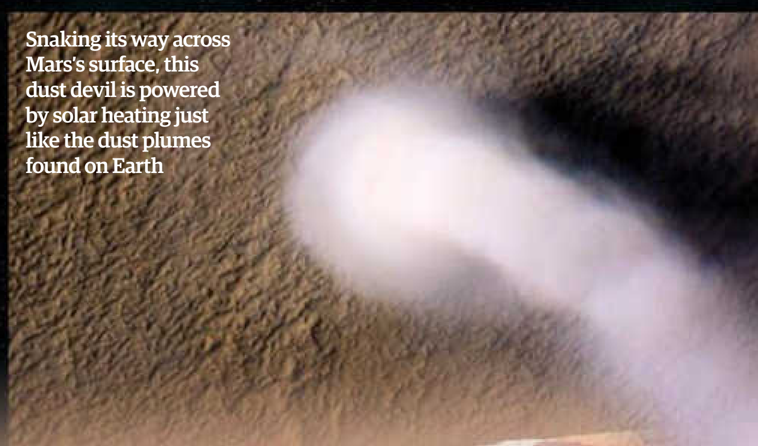


Kicking up dust

1. Desert dust
The dust storms, that frequently rise from the cold deserts of Mars, sometimes rage across the entire Martian globe, which crackle and snap with electricity.

2. Electrifying dust
It is possible that dust particles could be electrified in Martian dust storms when they rub against each other as they are carried by the winds, transferring positive (+) and negative (-) electric charges similar to the way that static electricity can be built up from shuffling across a carpet.

3. Strong swirls
Electric fields generated by the swirling dust are thought to be strong enough to break apart carbon dioxide and water molecules in the Martian atmosphere recombining to make reactive chemicals like hydrogen peroxide, which you'll find in bleach or other cleaning agents, and ozone. Some of these reactive chemicals are likely to have accumulated in the Martian soil over time.



Snaking its way across Mars's surface, this dust devil is powered by solar heating just like the dust plumes found on Earth

How do dust storms form?

1. Heating up the atmosphere
The absence of clouds or water means that radiation cannot be reflected back into space and the thin atmosphere close to Mars's surface becomes hotter than the atmosphere above it.

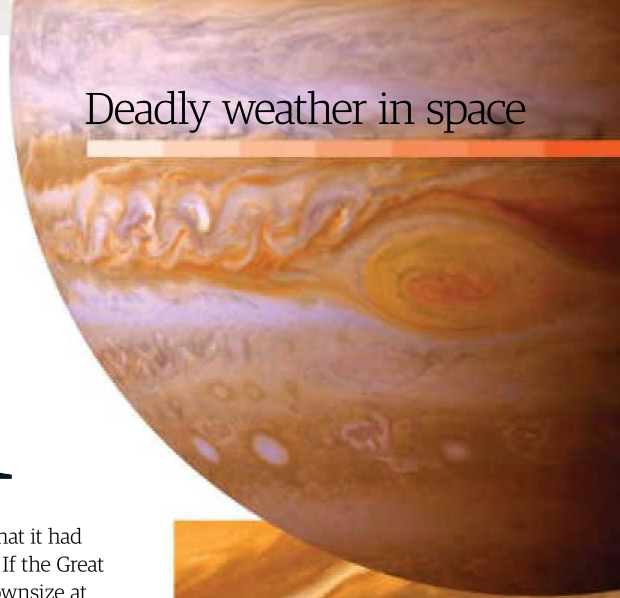
2. Picking up the dust
As the atmosphere is heated dust is lifted into the air and, after absorbing more sunlight, the dust warms up the atmosphere further, propelling more dust into the air.

3. The storm begins
The change in temperature creates winds, swirling at great speeds of 96 to 193km/h (60 to 120mph), capable of dominating the entire planet.

4. Dusty dirt devils
As well as the gigantic dust storms, Mars's surface is also raked with frequent, and strong, dust devils.

WHERE DOES THIS HAPPEN?

SUN · MERCURY · VENUS · EARTH · MARS · JUPITER · SATURN · URANUS · NEPTUNE · BEYOND SOLAR SYSTEM



Hurricanes bigger than Earth

Easily one of the most famous storms in the Solar System, Jupiter's Great Red Spot is so large that it is visible through many Earth-based telescopes.

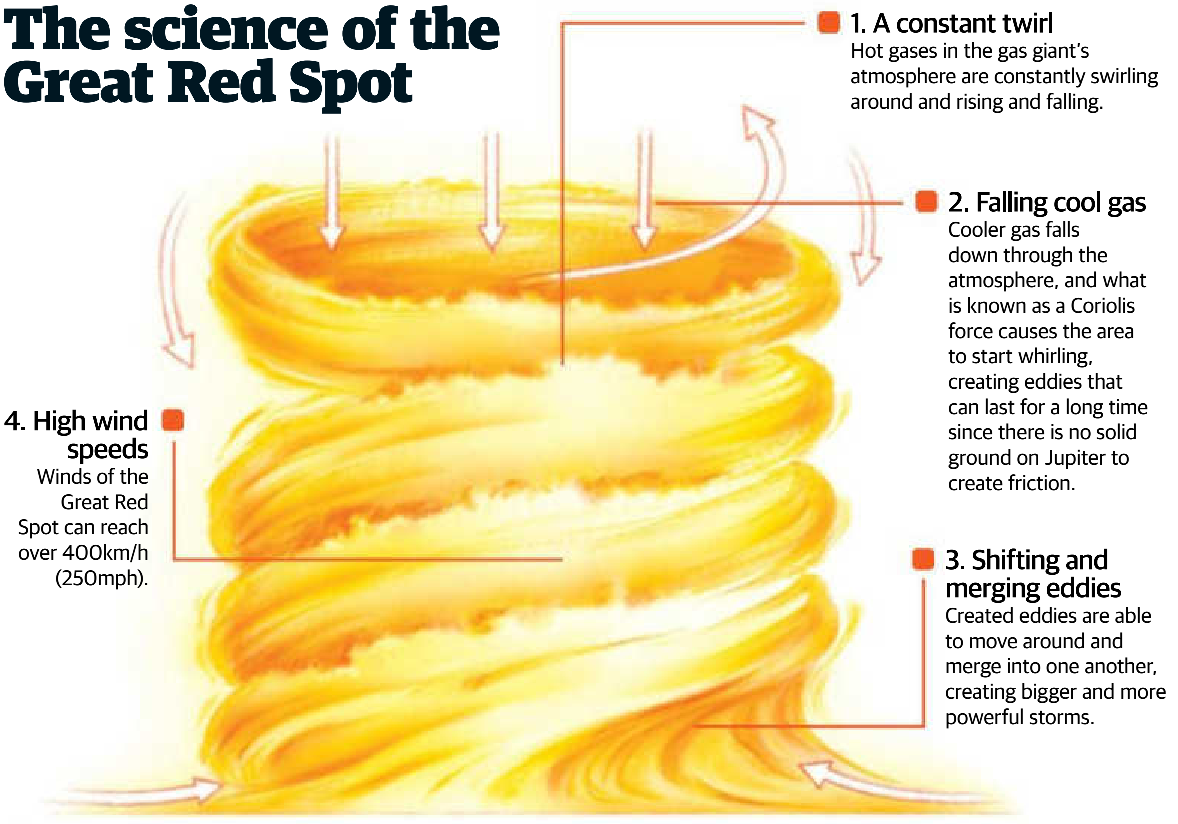
The Great Red Spot is thought to have been in existence for at least 340 years. The oval red eye rotates in an anticlockwise direction due to the crushing high pressure on the planet. Winds can reach over 400 kilometres per hour (250 miles per hour) around the spot, however, inside the storm they seem to be nearly nonexistent. And that's not all, this complicated weather system has an average temperature of about -162 degrees Celsius (-260 degrees Fahrenheit).

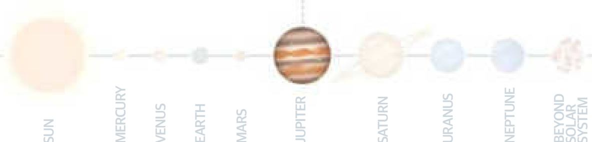
At around eight kilometres (five miles) above the surrounding clouds and held in place by an eastward jet stream to its south and a very strong westward jet flowing into its north, the Great Red Spot has travelled several times around Jupiter, but how did such a behemoth of a storm come to appear on the gas giant's surface?

The answer is not clear at this time despite the efforts of planetary scientists attempting to unravel the answers. However, what experts do theorise is that the storm is driven by an internal heat source, and it absorbs smaller storms that fall into its path, passing over them and swallowing them whole. Another thing that they also know is that the Great Red Spot hasn't always been its current diameter. In 2004, astronomers noticed that the great storm had around half the 40,000-kilometre (25,000-mile) diameter that it had around 100 years before. If the Great Red Spot continues to downsize at this rate, it could eventually morph from an oval shape into a more circular storm by 2040. You might think that this well-known feature won't be sticking around for long as it becomes smaller, but experts believe that the great age-old storm is here to stay since it is strongly powered by numerous other phenomena in the atmosphere around it.

Storms like these are not out of place on Jupiter, whose atmosphere is a zigzag pattern of 12 jet streams, with blemishes of warmer brown and cooler white ovals in the atmosphere owed to storms as young as a few hours or stretching into centuries.

The science of the Great Red Spot





The white oval storm directly below Jupiter's Great Red Spot is about the diameter of Earth

It is thought that, between Jupiter's core and the cloud tops lies an ocean of liquid hydrogen

Interactions with other storms could give the Great Red Spot its monstrous energy

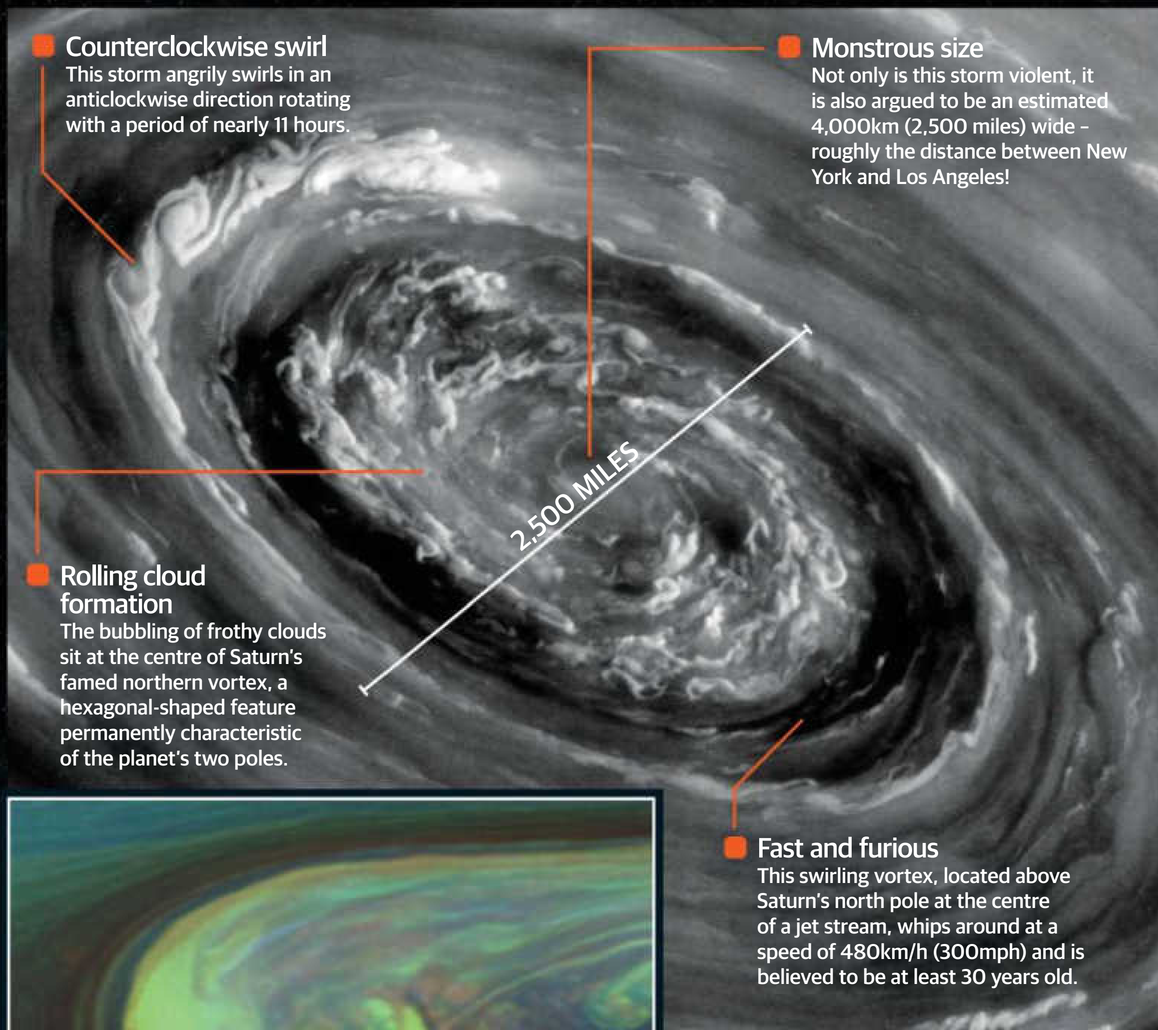
The violent polar vortex

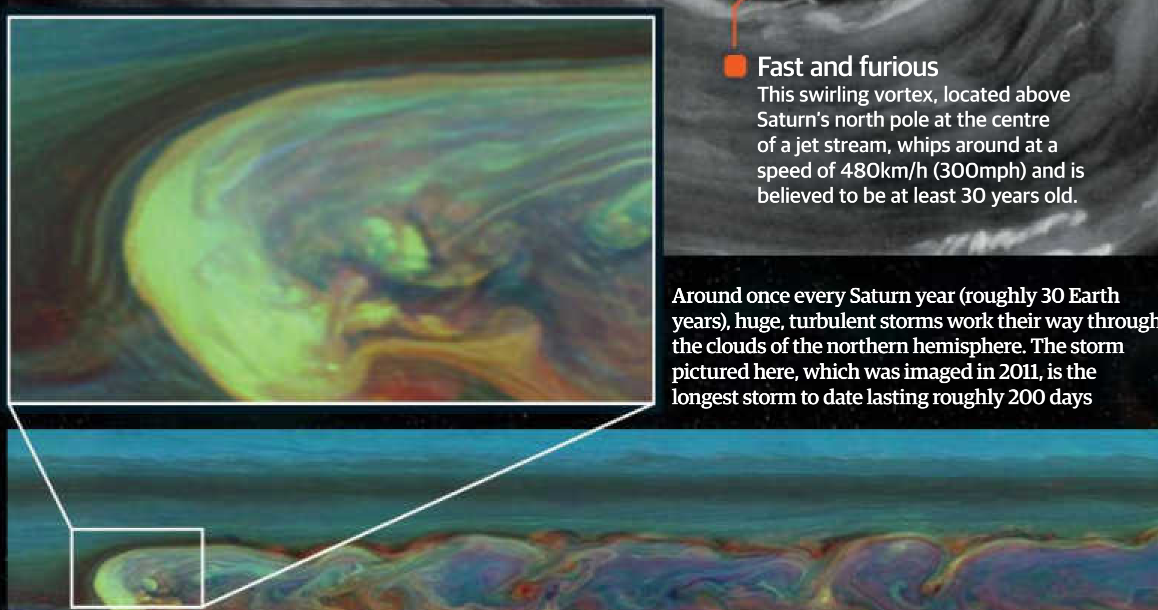
On the outside, Saturn almost looks like a calm, bland world, but once in a while, huge storms flare up on the ringed planet. From the short-lived Great White Spot of 1990, to the more recent storm of 2010, which grew into an atmospheric belt covering around 4 billion square kilometres (1.5 billion square miles), Saturn has proven to be a turbulent world. And what's more, the storms on Saturn are the second fastest in the Solar System, after ice giant Neptune, peaking at an impressive 1,800 kilometres per hour (1,120 miles per hour) and blowing in an easterly direction.

Temperatures on Saturn are normally around -185 degrees Celsius (-300 degrees Fahrenheit), but near the giant swirling polar vortex – a persistent cyclone taking pride of place at the ringed planet's south pole – temperatures start to warm up, and while the climate doesn't reach high enough for a suntan, this -122 degrees Celsius (-188 degrees Fahrenheit) vortex is the warmest spot on Saturn, with a powerful jet stream smashing its way through this terrifyingly fierce feature.

Saturn's north pole also has a giant storm of its own surrounded by a persistent hexagonal cloud pattern. Spotted in 1980 and 1981 during the Voyager 1 and Voyager 2 flybys, Saturn's hexagon, complete with six clear and fairly straight sides, is estimated to have a diameter wider than two Earths. The entire structure rotates almost every 11 hours.

Sighted much more closely by NASA's Cassini spacecraft in 2009 as springtime fell on the ringed giant's northern hemisphere, experts believe that the storm could have been raging for at least 30 years, whipping around at over 480 kilometres per hour (300 miles per hour) in a counterclockwise direction and disturbing frothy white clouds in its wake.





Around once every Saturn year (roughly 30 Earth years), huge, turbulent storms work their way through the clouds of the northern hemisphere. The storm pictured here, which was imaged in 2011, is the longest storm to date lasting roughly 200 days

WHERE DOES THIS HAPPEN?

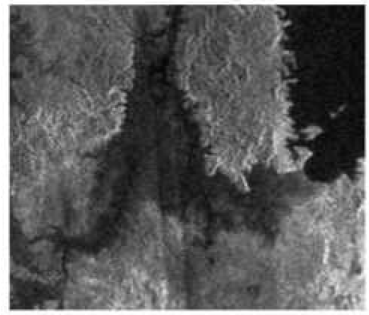
Deadly methane rain

With a surface pressure almost one and a half times that of Earth's, Titan's atmosphere is slightly more massive than our planet's overall, taking on an almost chokingly opaque haze of orange layers that block out any light that tries to penetrate the Saturnian moon's thick cover.

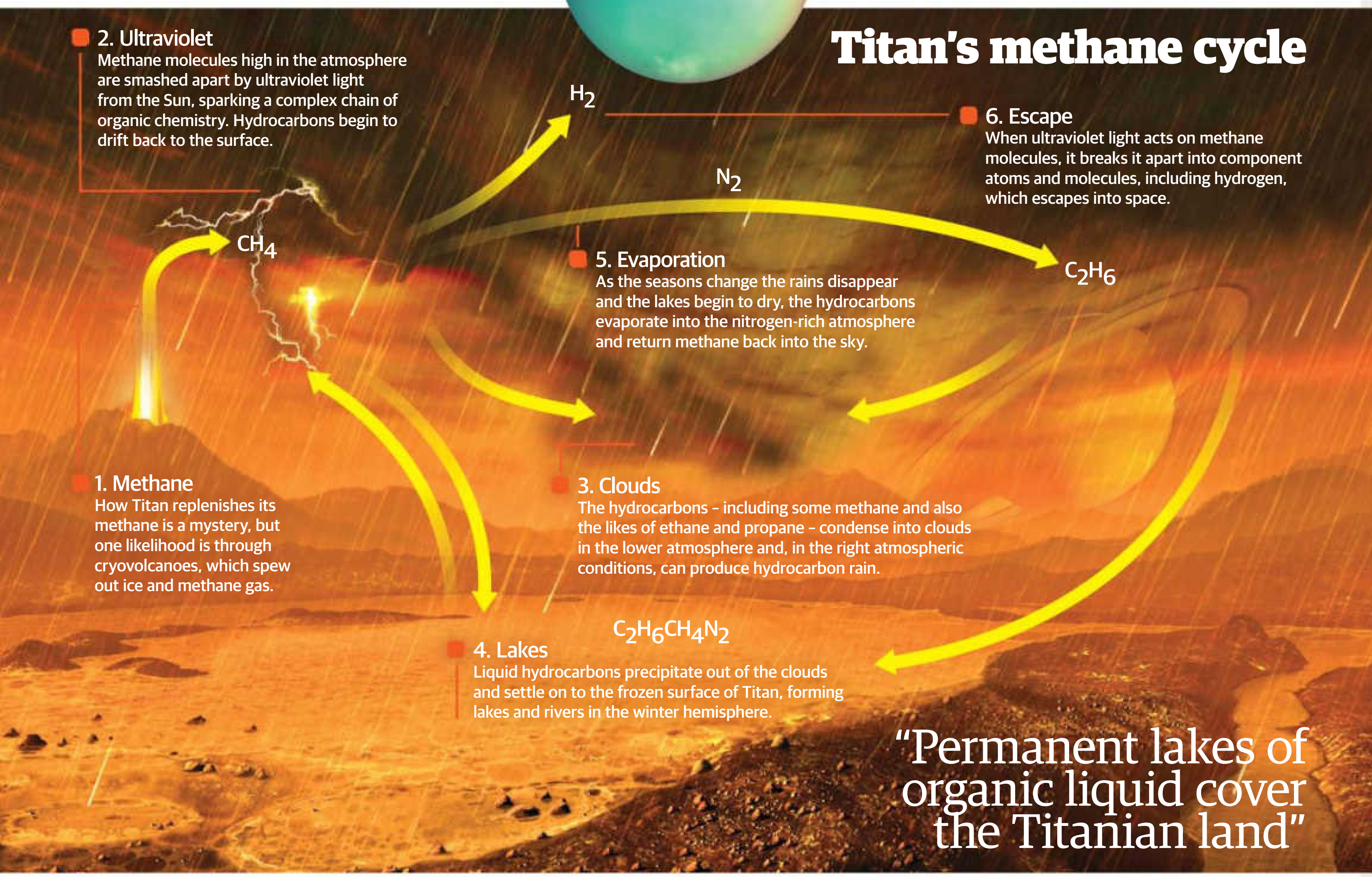
Titan is the only other world, other than Earth, where liquid rains on a solid surface. However, rather than the water that we are used to falling from the skies above us, pooling into puddles and flowing as streams and rivers, this moon's rains fall as liquid methane - liquid hydrocarbons that add more fluid to the many lakes and oceans that already cover the surface. And it is thanks to the moon's complex methane cycle, similar to the natural processes found on Earth, that this is possible.

Rain falls quite frequently on Earth, however, the same can't be said for some regions on Titan. Springtime brings rain clouds and showers to Titan's desert with the moon only experiencing rainfall around once every 1,000 years on its arid equator. However, these rain showers certainly make up for the lack of activity by dumping tens of centimetres or even metres of methane rain on to the Titanian surface.

At the poles of the moon its a completely different story, however. Methane rain falls much more frequently, replenishing the lakes of organic liquid covering the Titanian land.



Titan's lakes and rivers of liquid hydrocarbon are thought to be fed by methane rains brought about by the moon's complex methane cycle



Winds at twice the speed of sound

We've all got stuck out in or witnessed very strong winds here on Earth, from gusts that turn your umbrella inside out to tornadoes that rip up everything in their path. You might think these winds are a force to be reckoned with, but unless you've had a day floating around the gaseous atmosphere of ice giant Neptune you haven't seen anything yet!

You might think that Neptune's distance from the Sun, which creates temperatures as low as -218 degrees Celsius (-360 degrees Fahrenheit), would mean a world frozen solid by the subzero climate with not much going on in terms of weather. However, you would be incorrect. The winds that race through its hydrogen, helium and ammonia-laden atmosphere can reach maximum speeds of around 2,400 kilometres per hour (1,500 miles per hour), making this dark horse probably the most violently stormy world in the Solar System, and making our most powerful winds look like light breezes.

Neptune's fastest storms take the form of dark spots, such as the anticyclonic Great Dark Spot in the planet's southern hemisphere and the Small Dark Spot further south – thought to be vortex structures due to their stable features that can persist for several months – as well as the white cloud group, Scooter.

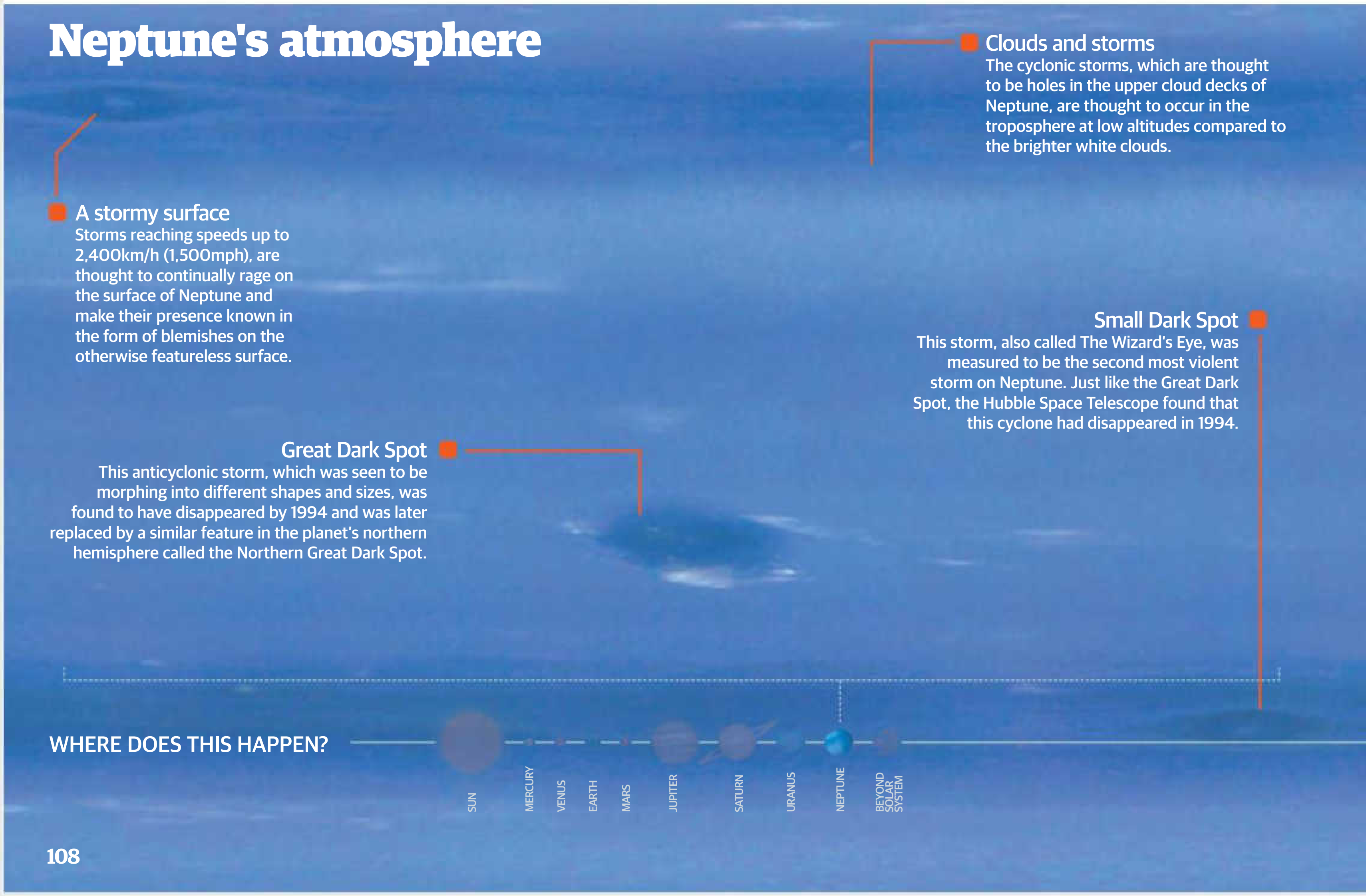
So what causes these winds? Neptune might be extremely frosty, but astronomers think that the freezing temperatures might be responsible; decreasing friction in the gas giant to the point where there's no stopping those super-fast winds once they get going.

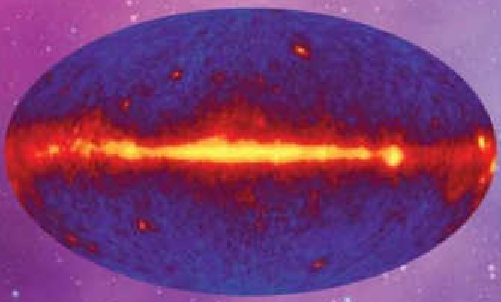
Delving into its layers of gas, we find another possibility pointing to just how these active storms came about as the temperature starts to rise. As things get more snug closer to the centre, the internal energy could be just what is driving the most violent storms that we've ever witnessed.

"The most violently stormy world in the Solar System"

Long bright clouds on Neptune's surface are similar to cirrus clouds on Earth

The gas giant's atmosphere as imaged by the Voyager 2 spacecraft in 1989





An all sky gamma ray map taken by the Compton Gamma Ray Observatory (CGRO)

Deep space: Lethal gamma rays

While gamma-ray bursts (GRBs) are short-lived, they can pack a punch of energy hundreds of times brighter than your standard supernova

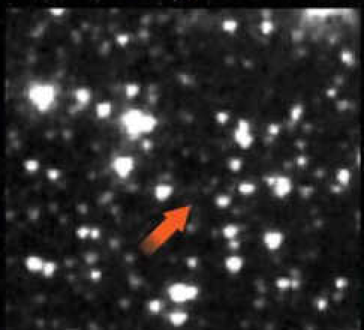
Releasing more energy in a mere ten seconds than the Sun will during its entire 10 billion-year lifetime, gamma-ray bursts reign supreme as the most deadly source of radiation known to man, pipping X-rays to the post.

Taking a trip just outside of the Earth's atmosphere, you'll find that gamma rays are everywhere, however, one of the greatest difficulties in detecting gamma-ray bursts is their incredibly short life span, lasting from just a fraction of a second to over 1,000 seconds. While they can't be seen by our visible light-sensitive eyes, space observatories such as NASA's Fermi Gamma-ray Space Telescope, which is currently performing observations from low Earth orbit, paints a picture of a gamma ray cosmos, proving just how exotic and fascinating our universe is.

But such a high level of radiation doesn't just come out of nowhere, there are many phenomena occurring deep in space, spilling out gamma rays from every pore of the hottest regions of the universe. These hot regions produced in the hearts of solar flares, the explosion of supernovas, neutron stars, black holes and active galaxies, provide these sources.

Back here on Earth we are protected from these bursts of gamma rays by our planet's atmosphere as, unless you're wearing a suit of lead, any interaction with this ionising radiation could prove disastrous as they penetrate through the human body destroying every cell in its path.

But what would happen to life on Earth if we happened to be in the firing line of some intense gamma ray spewing from phenomena such as the nearby explosion of supernovas, an off-the-scale burst from a solar flare destroying the ozone layer, or perhaps the collision between two nearby neutron stars? The answer is not a pleasant one as exposing life as fragile as ours to such a harsh environment would quickly change our currently perfectly balanced world into a deadly orb setting in motion a mass extinction, picking off and destroying life as we know it.

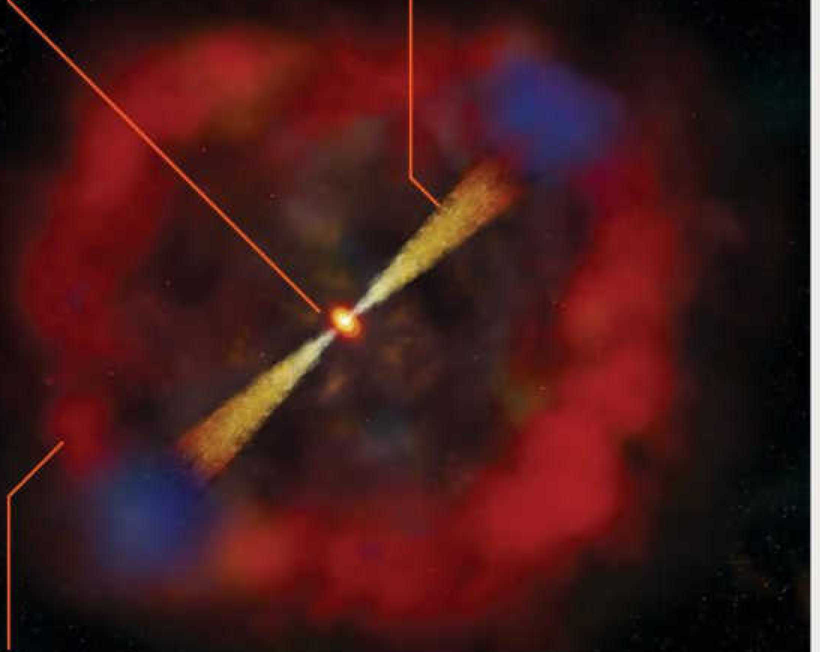


Gamma-ray bursts (GRBs) are gigantic blasts of light whose afterglows fade incredibly fast, lasting anywhere from just a few hours to a few days

Gamma ray formation

1. Rapidly rotating black hole
The spinning black hole, surrounded by a swirling disc of matter, is thought to be created by the collapse of a massive star's core.

2. High energy jets
Energetic particles from the rotating black hole shoot out in the form of high energy jets of excited particles.



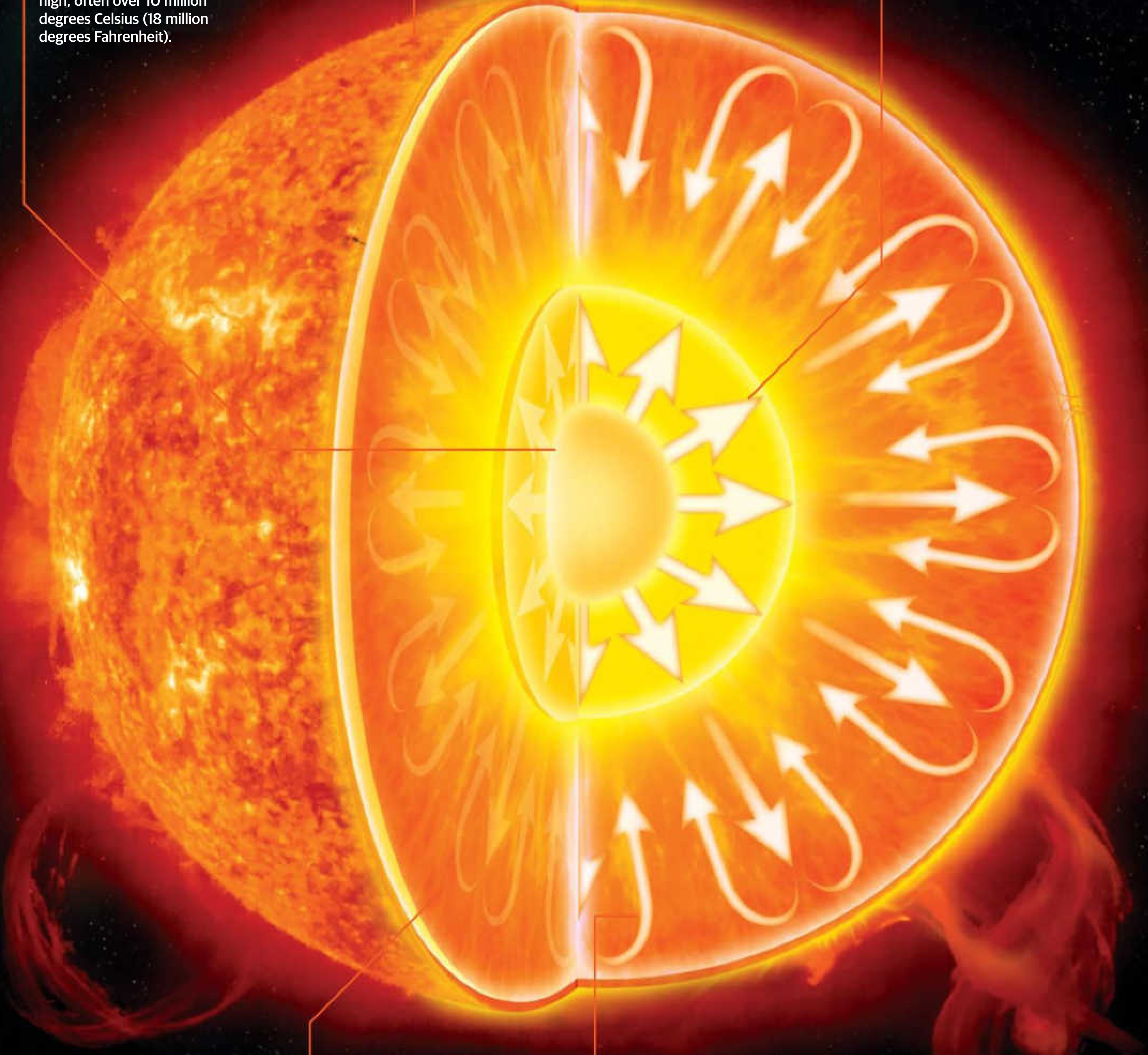
3. Supernova shell
The collapse of the massive star's core causes an explosion that ejects the outer layers of the star at high speeds, producing a shell. The interaction of the jet with this supernova shell produces an X-ray afterglow which can last for days or even months.

Anatomy of a star

Core
The core of stars is where the vast majority of their nuclear fusion reactions take place. Temperatures are incredibly high, often over 10 million degrees Celsius (18 million degrees Fahrenheit).

Magnetic field
Magnetic fields permeate all stars, with magnetic field lines arranged according to local conditions. Earth's Sun has a dipole magnetic field. These fields are commonly distorted by the star's internal dynamo.

Radiative zone
Each star has a radiative zone where energy from the core is directly radiated outwards through its gaseous material. Low-mass stars have radiative inner layers, while high-mass stars have radiative outer layers.



Subsurface flows
Subsurface flows are driven by both the distorting effect of the star's dynamo and also, on low-mass stars, by large convection zones that unstably transfer energy to the near surface in circular motions.

Convection zone
Driven by the fluid motion within the star's shells, convection zones are the secondary energy transportation process within stars. They only occur when radiative heat transfer is ineffectual, due to a high opacity of shell material.

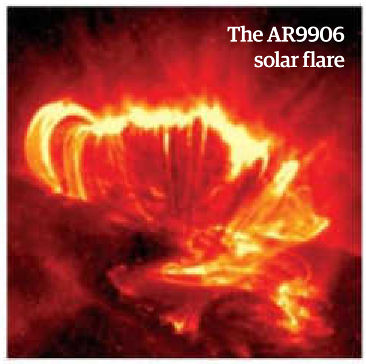
What happens inside a star?

While the surface of a star - known as its photosphere - appears a busy place, it is nothing compared to its interior, which is a hive of physical processes

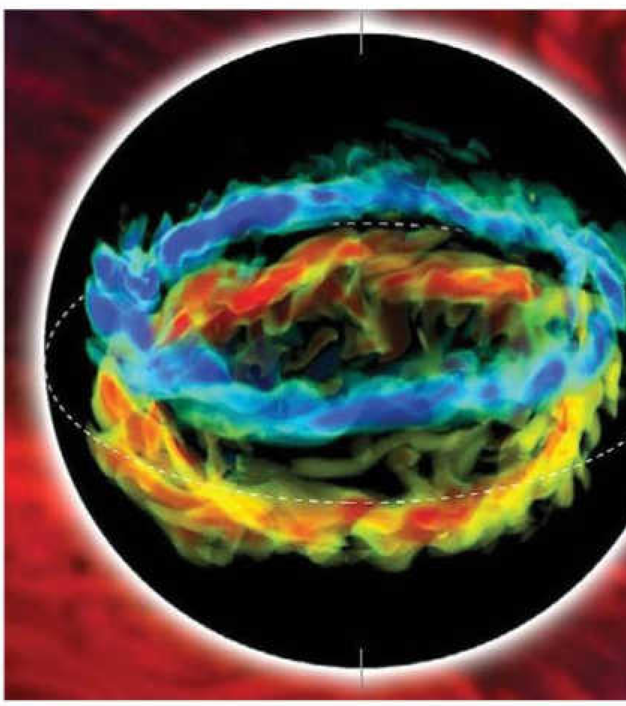
First, there is the process of hydrostatic equilibrium, which largely determines the star's density structure and is a counteracting sequence where the star's internal pressure gradient pushes against and counteracts the force of gravity. In essence, this determines the stability of the star's shell structure, its various rings of material (such as plasma) and forces emanating from the core. Without this stability, the various shells of the star will either contract or expand. For a star like our Solar System's Sun, the hydrostatic balance is finely tuned, as the star has been stable for over 7 billion years. However, for a star such as red supergiant Betelgeuse, it is not, hence the uneven shell structure.

The second key physical process within stars is energy transportation, which is important as the temperature of its gas determines the density structure via its hydrostatic equilibrium. The transportation of energy within stars can happen via two processes, either by radiation or convection. In main sequence stars - such as our Sun - these processes are typically localised in radius to specific zones, with their position determined by the star's mass and shell opacity. Stars with masses over seven times that of the Sun are convective in their inner layers, while radiative in their outer ones due to their high internal mass. In contrast, stars with low mass, tend to be radiative in their inner layers but convective in the outer layers as their opacity is lessened due to their lower internal mass.

Finally, the third key process within stars is nuclear fusion, a series of reactions which occur primarily in the star's core (see the 'Fusion power explained' boxout for more information). These fusion reactions necessitate high temperatures in excess of 10 million degrees Celsius (18 million degrees Fahrenheit) and high densities greater than hundreds of grams per cubic centimetre. Interestingly, the more massive a star is the shorter its life span becomes, as the nuclear fusion in its core occurs at a far quicker rate despite the increased quantity of fusionable material. As such, stars of similar size to our Sun will have a main sequence of approximately 10 billion years, while a star ten times as massive would only last around 20 million years.



The AR9906 solar flare



Solar dynamos are created by different parts of a star rotating at different speeds

Stellar dynamos

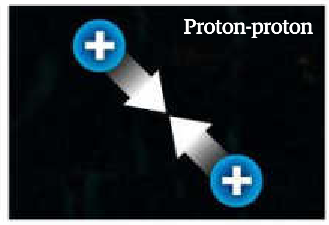
Many stars have a solar dynamo - vast rings of electrically conductive plasma that are charged through a shearing effect between different parts of the star rotating at different speeds. This shear charges the plasma to such an extent that they can warp the magnetic field lines.

This distortion is so severe that the magnetic field lines tend to be dragged along with the fluid in a whipping motion. Indeed, it is because of this distorting effect that many stars demonstrate sunspot cycles, with the star's dynamo extending its field lines so much that they pierce the surface of the photosphere.

Fusion power explained

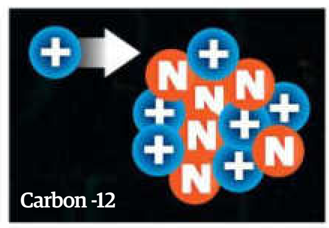
Proton-proton fusion

A nuclear fusion process that fuels stars with core temperatures less than 15 million Kelvin, proton-proton fusion is a common reaction. It entails two protons fusing, with one being transmuted to a neutron, forming deuterium. The deuterium then fuses with another proton, generating a helium nuclei, two of which then fuse to generate an alpha particle and the release of two protons.



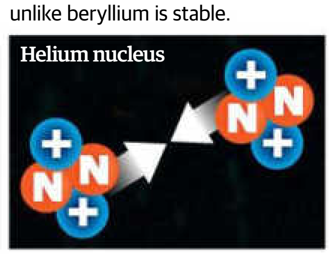
Carbon fusion

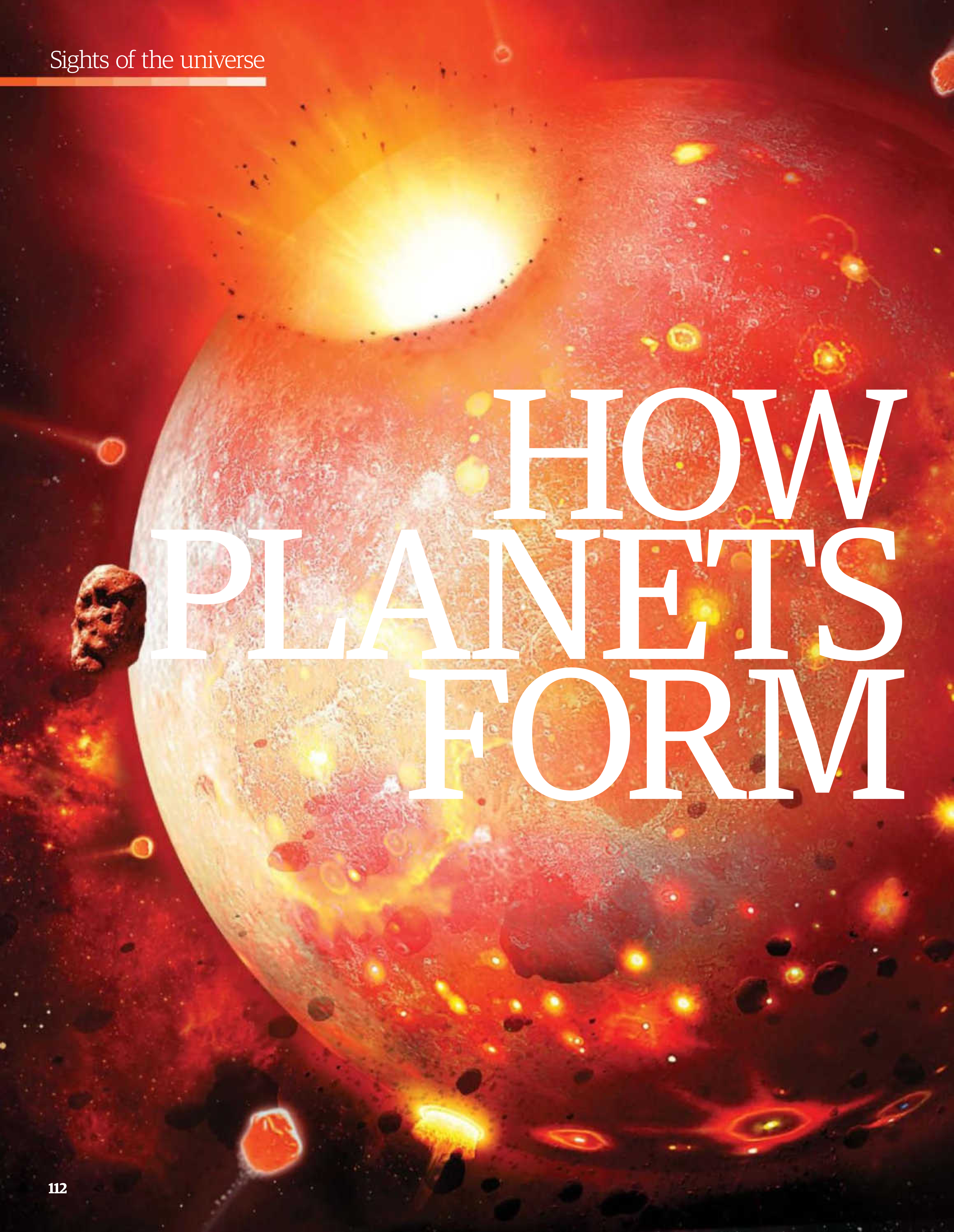
For stars with central temperatures over 15 million Kelvin, carbon fusion tends to be the dominant process. It revolves around adding protons to carbon and then nitrogen over multiple sequences. The end result is the generation of an oxygen-16 atom, which emits an energetic alpha particle. This is not a major part of the Sun's reaction cycle, but is prevalent in the star Sirius.



Helium fusion

If the core temperature of a star exceeds 100 million Kelvin, as is typical of red supergiant stars, then helium-helium can become the dominant reaction. This involves two helium nucleuses fusing to create beryllium-8 and emitting gamma rays, before the beryllium-8 fuses with another helium nucleus and generates carbon-12, which unlike beryllium is stable.





HOW PLANETS FORM

Discover how our home, along with our Solar System neighbours and every other planet in the universe, was born from a chaotic cloud of dust and gas

In a sense, planetary birth is a side effect of a larger birth: the formation of a star. Stars form from nebulas, massive clouds of gas and dust dominated by hydrogen and helium. Now and then, a disturbance in a nebula concentrates an area of gas and dust into a denser knot of material. If the knot is big enough and dense enough, it will exert enough gravitational pull to collapse in on itself. The huge volume of super-dense gas concentrates at the knot's centre, and the gravitational energy heats it up to form a protostar. With sufficient mass, the energy of the protostar increases, eventually initiating a nuclear fusion reaction and graduating to a proper star.

Meanwhile, according to the solar nebula theory, surrounding gas and dust form a protoplanetary disc, or proplyd, around the protostar. When the protostar first begins to form, the surrounding material is still an unordered, slowly churning cloud. But the protostar's growing gravitational pull accelerates the cloud's movement, causing it to swirl around the centre. As the swirling mass speeds up, it flattens out, forming a thin disc, packed with all the material that will eventually coalesce into planets.

As well as explaining how planets form, the solar nebula theory also explains why solar systems take the form they do. The planets all revolve in the same direction around a central star, in the same plane, because that's how the material disc originally swirled around the protostar.

Exactly how it all comes about is still up for debate, and there may actually be many different planet formation processes. The prevailing understanding, called the accretion model, is that planet formation begins when individual bits of matter in the disc clump together into bigger chunks. The accretion model seems to be correct at least in the case of rocky terrestrial planets, like Earth and Mars, which form from silicates and heavier metal, such as iron and nickel.

Astronomers generally agree that a planet like ours begins with an invisible piece of dust. Microscopic grains in the disc grow by condensation, the same process behind snowflake formation. In condensation, individual heavy gas atoms or molecules stick to a grain, rapidly expanding its size into a more substantial solid particle.

When the particles are very small and light, turbulent gas motions stir them up, swirling them outside the flat plane of the proplyd. But when they reach sufficient mass they're heavy enough to settle into the relatively thin rotating disc. In the crowded disc, particles collide more frequently, speeding up the growth of larger and larger chunks.

At about the point a chunk of solid matter grows to a kilometre across, it graduates to a planetesimal. A planetesimal is massive enough that its gravitational pull attracts smaller chunks of matter, accelerating the rate of growth. The result is a relatively small number of planetesimals steadily capturing the smaller chunks and particles in the disc.

When a terrestrial planetesimal grows large enough, the energy of

many collisions along with radioactive material it's accreted heat everything to melting point. As a melted mass, the planetesimal's structure can reform. In a process called differentiation, the force of gravity concentrates the melted metals into an inner core, surrounded by an outer crust of lighter rocky silicates. The result is a protoplanet, an asteroid-like mass with distinct layers. Over time, gravity evens out the protoplanet's shape, forming it into a sphere.

A terrestrial planet might form an atmosphere layer through outgassing. Essentially, heat from the planet's interior core unlocks gases trapped in the planet's solid and molten interior. Planets might then add to this atmosphere through encounters with other solar system bodies.

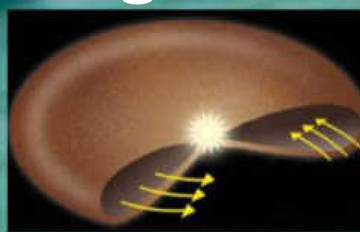
As the diversity of our own Solar System demonstrates, atmospheres vary a great deal. Any particular atmospheric recipe requires not only the right mix of planetary matter, but also a precise balance of planetary size and proximity to the central star. When a smaller planet orbits very close to a star, like Mercury, the Sun's heat blasts away any atmosphere, leaving a barren rock. Meanwhile, a planet like Mars is so far from the Sun that all its water is locked up in ice. But just a bit further in, you get Earth – a planet that's the right size and in the right position to form a robust atmosphere that could support life.

While there is general agreement among astronomers that terrestrial planets formed along these lines, the origins of Jovian gas giant planets, like Jupiter and Saturn, are less certain. One possibility is they start out the same basic way as terrestrial planets, steadily accreting solid matter to form a massive protoplanet. If it grows large enough – about 15 times the size of Earth – such a protoplanet exerts a strong enough gravitational pull to capture hydrogen and helium gas in the proplyd. The gaseous mass then sweeps up more material, growing into a Jovian behemoth.

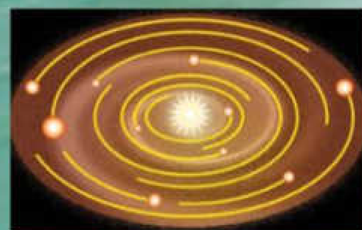
There is a relatively small supply of heavy metals and silicate in a proplyd, making it unlikely that a protoplanet could accumulate enough metal and rocky material to reach the size necessary to hold on to hydrogen and helium gas. Instead, this model says, the initial planetary core of a Jovian planet forms out of frozen hydrogen compounds, such as methane, ammonia and water. Near the centre of a proplyd, the developing protostar makes it too hot for hydrogen

Origins of a solar system

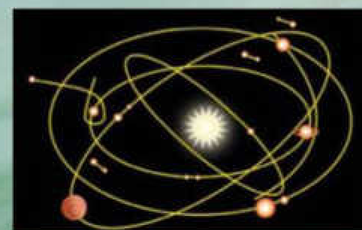
Gas giant, the accretion model



1. Dirty snowballs
Dust grains and bits of frozen hydrogen compounds condense and then collide and stick together, forming bigger and bigger icy planetesimals.

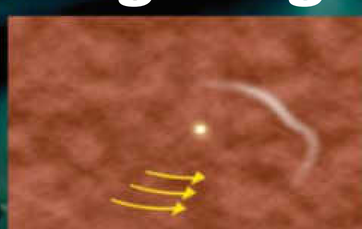


2. Capturing gas
Some planetesimals grow so big that their gravitational pull captures hydrogen and helium gas in the protoplanetary disc.



3. Too big to fail
The gas giants grab a huge supply of the disc's hydrogen and helium gas. Their massive gravity pulls in or scatters remaining planetesimals.

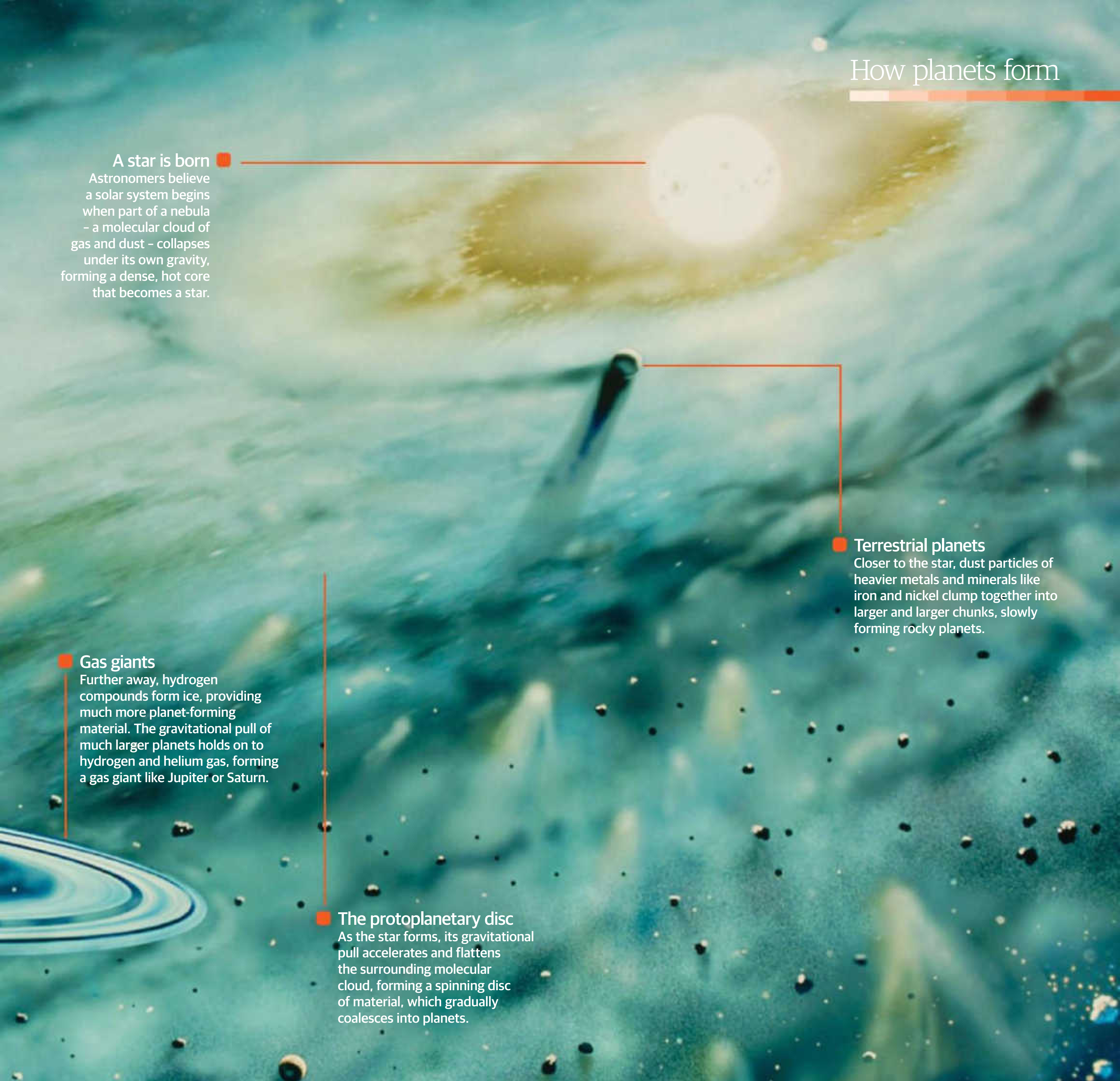
Gas giant, gas collapse model



1. Concentrations in the disc
In the disc of gas and dust that forms around a protostar, the dynamics of the rotation cause uneven distribution of hydrogen and helium gas.

2. 'Instant' planet
A clump of dense gas collapses under its own gravity to form a gaseous planet. The new planet picks up dust and ice, which collect into a solid core.

3. Glutton for gas
As the planet makes its way around the disc, its strong gravitational pull sweeps up more gas, making it bigger and bigger.



A star is born
Astronomers believe a solar system begins when part of a nebula – a molecular cloud of gas and dust – collapses under its own gravity, forming a dense, hot core that becomes a star.

Terrestrial planets
Closer to the star, dust particles of heavier metals and minerals like iron and nickel clump together into larger and larger chunks, slowly forming rocky planets.

Gas giants
Further away, hydrogen compounds form ice, providing much more planet-forming material. The gravitational pull of much larger planets holds on to hydrogen and helium gas, forming a gas giant like Jupiter or Saturn.

The protoplanetary disc
As the star forms, its gravitational pull accelerates and flattens the surrounding molecular cloud, forming a spinning disc of material, which gradually coalesces into planets.

A terrestrial world is born

1. Let's stick together
Mineral and metal dust particles throughout the molecular cloud collide and clump together, forming larger rocky particles.

2. Running with the crowd
As trillions of these particles rotate around the developing star, they're constantly colliding, forming bigger asteroid-like pieces through accretion.

3. Forming a planetesimal
When a rocky chunk grows to about 1km across, its gravitational pull is able to attract other pieces, speeding up the accretion process.

4. Graduating to a protoplanet
Intense heat melts the rocky material. During melting, elements like iron and nickel concentrate at the centre of the planet, giving it distinct layers.

compounds to condense into frozen solids. They remain in gaseous form and so do not accrete to developing planetesimals. But if you move far enough away from the hot protostar, past what's called the frost line, the temperature drops low enough that hydrogen compounds can freeze. With a much more abundant supply of solid material, large icy protoplanets can form and capture the swirling hydrogen and helium gas.

The organisation of our Solar System supports this theory. The inner planets, Mercury, Venus, Earth and Mars are all relatively small and rocky, suggesting forming giant icy or gaseous planets wasn't possible close to the Sun, while the outer planets, Jupiter, Saturn, Uranus and Neptune, are much larger.

The chief argument against the accretion model for Jovian planets is timing. In well-supported models of solar system evolution, there simply isn't enough time to grow the massive icy cores before the developing solar system loses the bulk of its hydrogen and helium gas supply. While the lighter gases are the dominant material during the proplyd's early life, their days are numbered. In the case of our own Solar System, some 10 million years after the Sun first formed as a protostar, the energy of nuclear fusion reactions likely produced powerful solar winds that would have cleared out the remaining gas in the proplyd. That's a tight window for Jovian gas giants to form.

And neighbouring stars may lead to the window shrinking even further. Astronomers believe that stars generally form in clusters that contain massive, hot stars. Calculations say radiation from these stars would accelerate the evaporation of gaseous material in nearby proplyds, shrinking the period of plentiful hydrogen and helium to between 100,000 and 1 million years. That doesn't appear to be enough time for a Jovian gas giant to form through the accretion model, yet observations of distant solar systems show that these gas giants are very common.

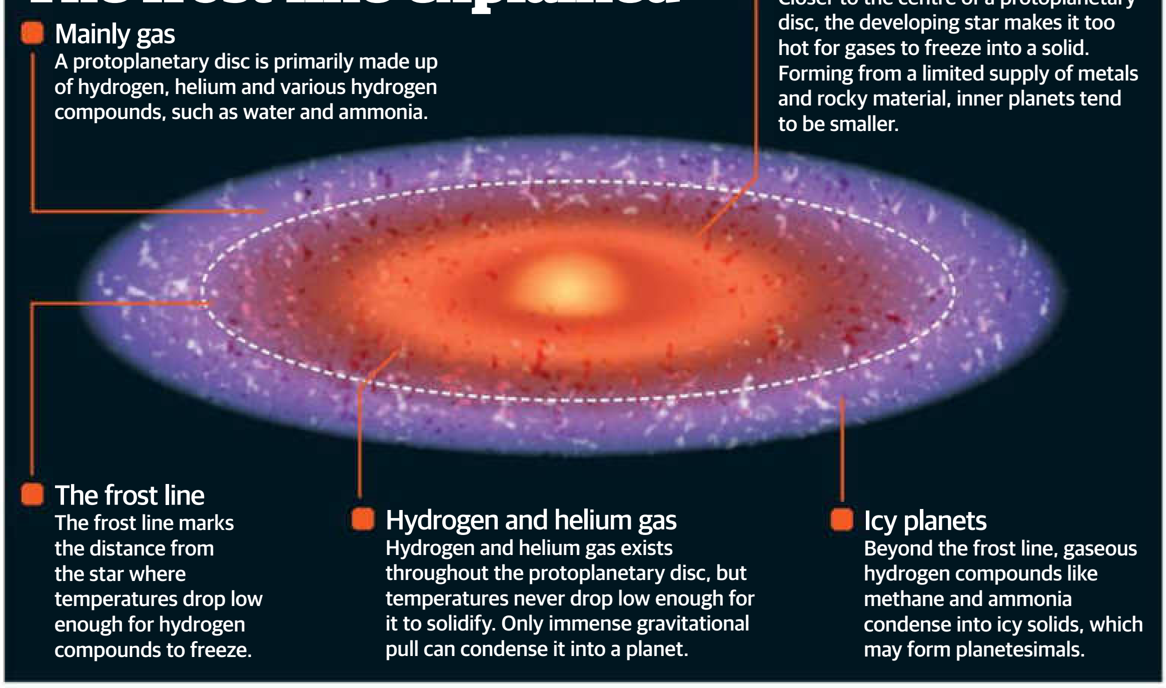
An alternative theory, known as the gas collapse model, presents a faster formation scenario. According to this model, gas giants form directly from the swirling hydrogen and helium in a developing proplyd. As the material revolves around the protostar, turbulence in the disc distributes it unevenly. This unevenness forms knots of dense gas. When enough gas is concentrated tightly enough, its dense mass causes it to collapse in on itself, forming a giant gas ball. To put it another way, the gas giant is like a failed star. It forms the same basic way as the protostar, but doesn't have sufficient mass and energy for a nuclear fusion reaction.

The embryonic planet's gravitational pull takes over from there, sweeping up massive amounts of gas, as well as any solids in the vicinity, quickly adding to its bulk. Collected ice and metals condense at the planet's centre, forming a solid core after the gas has accumulated, rather than before. The whole process might happen as quickly as a few hundred years.

Observations of Jovian exoplanets (planets located outside our Solar System) have given some credence to this model - or at least challenged the Jovian accretion model. In the wave of exoplanet discoveries over the past 25 years, one of the biggest surprises has been the so-called 'hot Jupiters', Jovian gas giants that orbit very close to their suns. These planets would seem to contradict the notion that gas giants only form beyond the frost line. However, they may have formed further out, but then migrated towards their suns.

A host of exoplanet discoveries have given astronomers a much bigger picture of the range of possible planets, which has yielded new clues about how planets might form. But examining the end results can only tell them so much. Fortunately, we're likely entering a new era of direct proplyd observation, thanks to advances in telescopic technology. The new Atacama Large Millimeter/submillimeter Array (ALMA) radio telescope in Chile, which should be fully operational in March, has already yielded unprecedented images of planet formation in progress. As new discoveries follow, astronomers expect to fill in more pieces of the puzzle, taking us ever closer to understanding how our planet, and by extension all of us, came to be.

The frost line explained



Types of planets

Terrestrial

Terrestrial planets like Earth and Mars are rocky planets with metal cores and high densities. They are smaller than gas giants and have slower rotation periods. In addition, their smaller size means they are less likely to have moons.

Gas giant

At a further distance from their orbiting star, gas giants are able to accrete more matter in their formation, giving them a large size and mass. For example, Jupiter is 11 times larger than Earth, and has a volume 1,300 times greater.

Dwarf planet

Smaller than a true planet, the difference between an asteroid and a dwarf planet comes down to its shape. To be a dwarf planet, a body must have sufficient mass to achieve hydrostatic equilibrium, when it will become spherical.

Planet formation in action

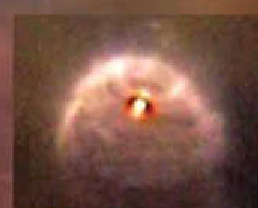
Our nearest star-forming region is the Orion Nebula, a massive cloud of gas and dust around 1,500 light years away. The striking nebula is visible to the naked eye - and positively breathtaking as seen through the Hubble Space Telescope. Hubble's sharp images, like this one from 2009, have revealed 42 protoplanetary discs (proplyds) where planet formation is now in progress. Theta^1 Orionis C, the nebula's brightest star, heats nearby proplyds, giving them a bright glow. Proplyds forming further away are too dim to see, but their dark dust blocks out parts of the bright nebula in the background, creating silhouettes astronomers can study.

132-1832
Developing far from Theta^1 Orionis C, 132-1832 is one of the darker proplyds in the nebula.

206-446
Astronomers believe this bright proplyd's distinctive ponytail-style plume is a jet of matter streaming out from the disc's centre.

180-331
Proplyd 180-331, another bright disc near Theta^1 Orionis C, also sports a flowing jet of matter, giving it a tadpole shape.

106-417
Stellar wind from the massive Theta 1 Orionis C interacting with gas has formed a shockwave around this ear-shaped proplyd.



181-825
But the best shockwave sculpture has to be 181-825's distinctive galactic jellyfish form.

231-838
Like 106-417, the bright proplyd 231-838 is surrounded by a shockwave, giving it a boomerang shape.

> "The origins of Jovian gas giant planets, like Jupiter and Saturn, are less certain"

How do planetary orbits work?

Which forces keep the planets of the Solar System in their paths around the Sun?

If the Sun disappeared tomorrow, Earth would soon become a very cold and dark planet and would tumble out of its orbit. It would follow a straight rather than a curved path, drifting away in whichever direction it was facing.

Thankfully, this won't happen any time soon. Even though the Earth only wants to go forward, the Sun's gravity stops it moving further away and holds it in orbit, doing the same for the Solar System's other planets, dwarf planets, comets and asteroids too.

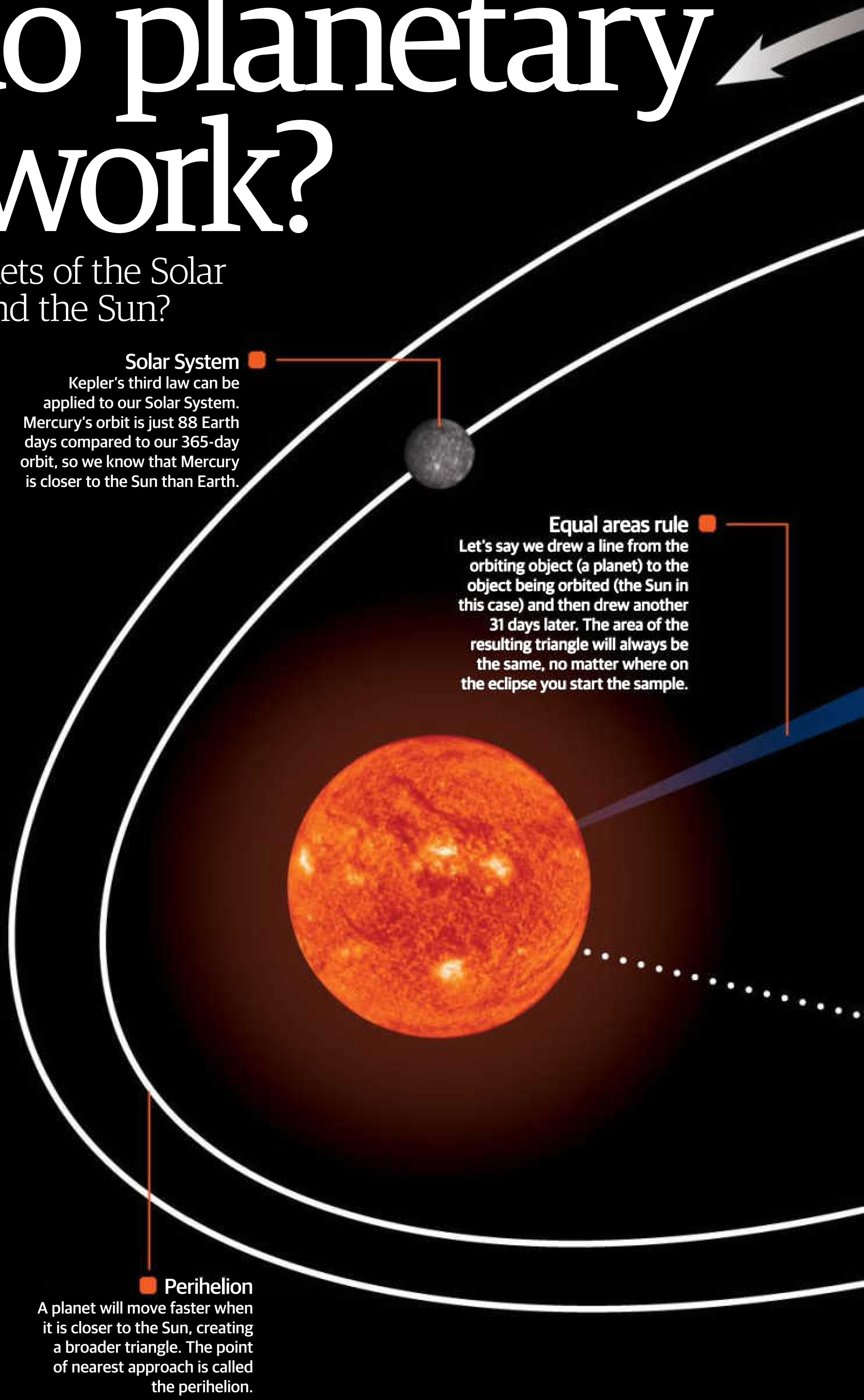
In doing so, the Sun exerts a centripetal force, pulling these falling bodies into an elliptical path around it. The stable orbits that result are a balancing act between the planet's forward motion and the gravitational pull exerted on it. At the optimum balance, although the body is constantly falling towards the Sun, it is moving sideways fast enough to ensure it does not collide with the Sun.

The same principle applies to satellites that orbit planets. Our Moon, for example, is affected by the gravity of the Earth as well as the Sun. It must remain at the required speed to stay in orbit and it cannot reach a speed that would enable it to pull free.

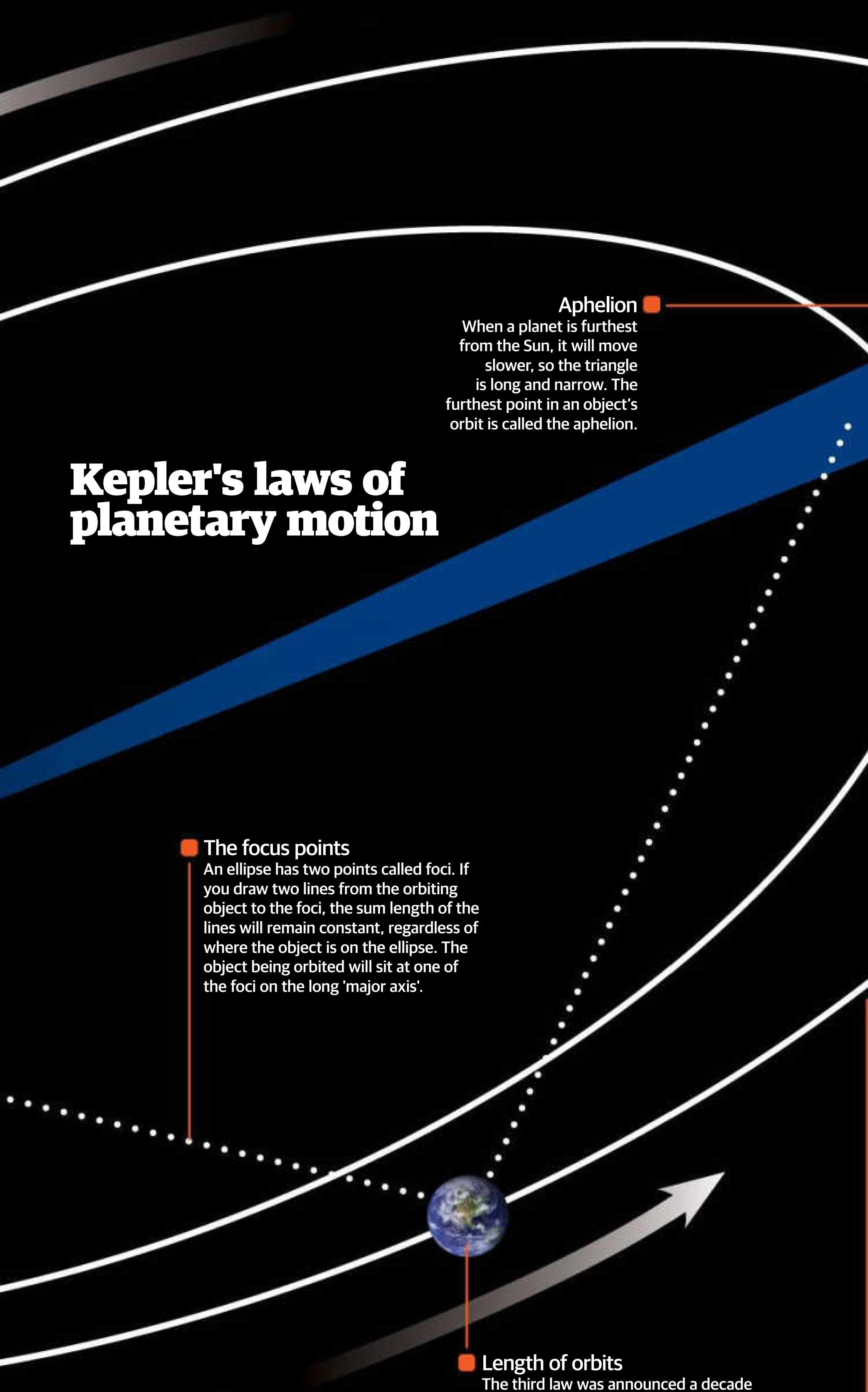
Any object in orbit around another, under the influence of gravity, acts in accordance with a set of laws described by the German mathematician and astronomer Johannes Kepler. These are referred to as Kepler's three laws of planetary motion and they date back as far as 1609.

The first law states that the planets move around the Sun in orbits shaped like ellipses. The second rule is that they sweep out equal areas of space in equal times as they orbit. Even though a planet changes speed as it orbits the Sun - the closer it is to the Sun the faster is travels and vice versa - if you were to draw a line from the centre of the planet to the centre of the Sun and then another at a later set period of time, it doesn't matter where the planet is in its orbit, the area of the 'slice' of its orbit ellipsis that it has covered will be the same.

Kepler's third law describes the relationship between the time it takes for a planet to orbit, and its distance from the Sun. His equation states that the square of the orbital period of a planet is proportional to the cube of its average distance from the Sun. So if you know how long it takes for a planet to go around the Sun, it is possible to work out how far away it is. Kepler's work has been hugely influential; it was his final law that led Isaac Newton to his work on gravity and the laws of motion.



Kepler's laws of planetary motion



Aphelion

When a planet is furthest from the Sun, it will move slower, so the triangle is long and narrow. The furthest point in an object's orbit is called the aphelion.

Elliptical orbit

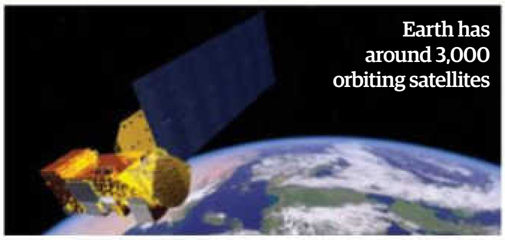
Johannes Kepler worked as an assistant to astronomer Tycho Brahe and was asked to define the orbit of Mars. He noted that all objects in orbit around another object follow an elliptical path and this became his first law.

The focus points

An ellipse has two points called foci. If you draw two lines from the orbiting object to the foci, the sum length of the lines will remain constant, regardless of where the object is on the ellipse. The object being orbited will sit at one of the foci on the long 'major axis'.

Length of orbits

The third law was announced a decade after the first and second, going into more depth on the movement of an orbiting object. If you know how long it takes for a planet to orbit the Sun, then you can work out how far away from our star it is.



Earth orbits

When satellites are put into space, they can do one of two things: stay above one particular area of Earth or circle the planet. The behaviour of the satellite is determined by its distance from Earth, and whether it is in a low, medium or high orbit. Objects in a low orbit move faster than those in a high orbit. Satellites for television, communication and weather are placed in a medium orbit where they can follow the same spot on the Earth. NASA's Aqua satellite, which gathers information about the Earth's water cycle, is in a low orbit, circling the planet in 99 minutes.

What are asteroids made of?

The physical properties of huge space-rocks whirling around the Sun could hold clues to the origins of the Solar System

Protecting Earth is one of the main reasons why scientists keep a close eye on asteroids, which are space rocks of all shapes and sizes that can be found scattered throughout the Solar System.

It's unclear how meteoroids, the rocks that become meteors when they crash into Earth's atmosphere, were generated from asteroids. Still, NASA isn't ruling a link out and is examining asteroids to learn more about how the Solar System was formed.

Since planetary scientists believe planets gradually grew from rocks crashing into each other, the asteroid belt between Mars and Jupiter could be made up of the leftovers of the early Solar System.

Therefore, ferreting out the secrets of asteroids could also give scientists clues as to how the Solar System came to be. Possibly, it could even reveal how the Earth was born.

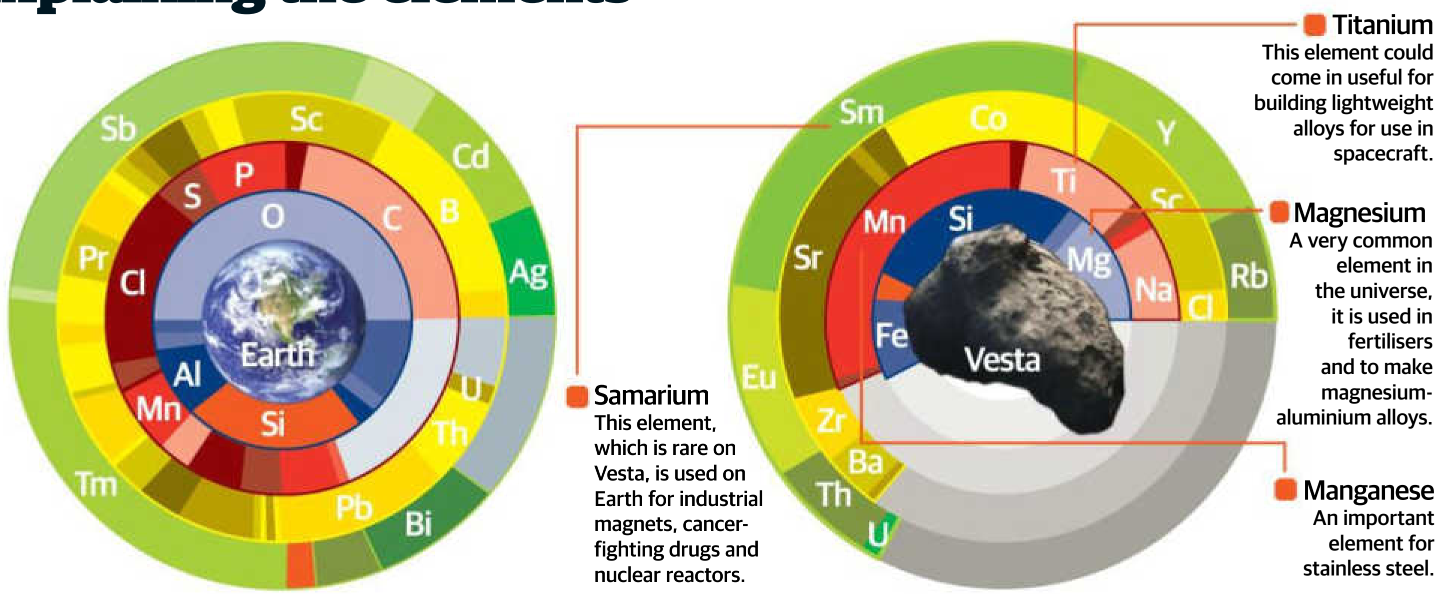
Studying asteroids is a challenge for scientists, however, because they are so small. A typical space rock is perhaps just a few metres across. However, the largest known asteroid in our Solar System, Ceres, is 950 kilometres (590 miles) in diameter and makes up a third of the mass of the known asteroid belt. However, through a telescope sitting on Earth, an asteroid of this size looks incredibly small. This makes asteroids difficult to see and study, but scientists are pretty crafty when it comes to getting information from a distance.

Most asteroids, according to NASA, can be classified in three groups: C-type (carbonaceous), S-type (siliceous) and X-type (various compositions). Around 75 per cent are C-type asteroids that lurk in the outer asteroid belt. They are very dark and probably lack helium, hydrogen and other lighter

"In 1995, there were only 335 known near-Earth asteroids, however, today there are more than 9,700 catalogued"

Asteroid Ida and its moon, Dactyl. The spacecraft Galileo discovered the small moon when it passed by the asteroid in 1994

Explaining the elements



Ag - Silver
Al - Aluminium
B - Boron
Bi - Bismuth
C - Carbon
Cd - Cadmium
Cl - Chlorine
Mn - Manganese
O - Oxygen
P - Phosphorus
Pb - Lead
Pr-Praseodymium
S - Sulphur
Sb - Antimony
Sc - Scandium
Si - Silicon
Th - Thorium
Tm - Thulium
U - Uranium

Ba - Barium
Co - Cobalt
Cl - Chlorine
Eu - Europium
Fe - Iron
Mg - Magnesium
Mn - Manganese
Na - Sodium
Rb - Rubidium
Sc - Scandium
Si - Silicon
Sm - Samarium
Sr - Strontium
Th - Thorium
Ti - Titanium
U - Uranium
Y - Yttrium
Zr - Zirconium

Asteroids can range from just a few metres wide to almost 1,000km in diameter

'volatile' elements. S-type asteroids, about 17 per cent of the population, make up most of the inner belt rocks in the asteroid belt. They're a little more reflective and are usually made of metallic iron mixed with silicates of iron and magnesium. Squeezed in between these asteroids are X-types, which are mostly made up of metallic iron asteroids and the like. These are found in the middle of the asteroid belt.

While most asteroids sit safely between Mars and Jupiter, some approach Earth and sometimes cross its orbit. Scientists think most of these asteroids were 'disturbed' into different orbits due to Jupiter's gravity or collisions with other asteroids.

There are three types of near-Earth asteroids. Amors cross the orbit of Mars, but don't get very close to Earth. Apollos cross Earth's orbit in a period of one year or longer, while Atens also cross the orbit but in a shorter time frame – a year or less.

In the past two decades, space agencies and observatories around the world have discovered thousands of these types of asteroids. In 1995, there were only 335 known near-Earth asteroids, however, today there are more than 9,700 catalogued, according to NASA.

Since scientists believe we have now found more than 90 per cent of threatening asteroids that are more than one kilometre (0.6 miles) in diameter, NASA is now emphasising the search for finding near-Earth objects of 140 metres (460 feet) or greater.

Still, a much smaller object can cause a lot of damage. The dinosaurs were probably wiped out by a small body just ten kilometres (6.2 miles) in diameter that hit the Mexico area about 66 million years ago.

In Russia this year, more than 1,000 people were injured when a house-sized asteroid – 17 metres wide (56 feet) – detonated in the atmosphere. The event caught both the public and astronomers by surprise, demonstrating we still have a lot to learn about predicting meteor strikes on Earth.

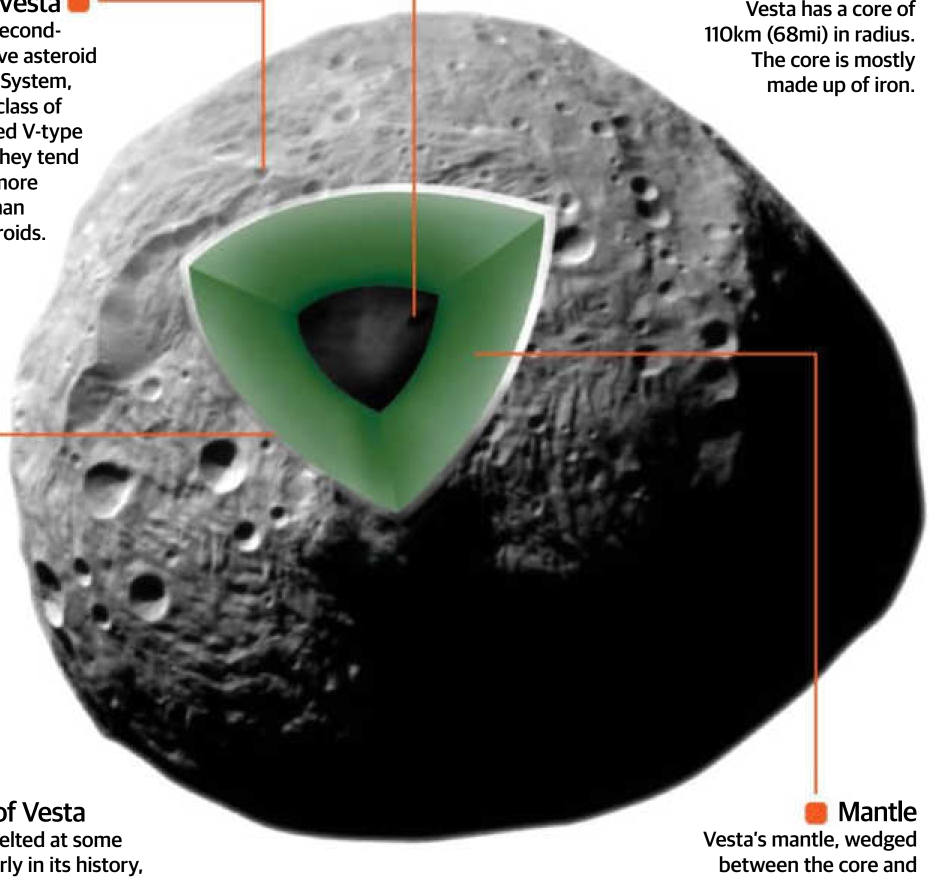
In more recent years, several space missions have ventured out to asteroids to get more information from closeup. NASA's Dawn mission, for example, scooted by the asteroid Vesta in 2011 and is now en route to Ceres.

Its closeup views revealed a battered world that, surprisingly, has some links to how the Moon was formed. Vesta and the Moon were each peppered by a population of space rocks ejected into the inner Solar System early in the Earth's history.

Both Jupiter and Saturn shifted their orbits in less than a million years. Their motions perturbed the asteroid belt and sent the rocks into planet-crashing orbits. This bombardment had been known about for decades – astronauts on the Apollo missions even discovered evidence of it on the Moon – but scientists didn't know until recently that Vesta had also experienced it.

The next step will be obtaining a sample of an asteroid and studying it here on Earth. Origins Spectral Interpretation Resource Identification Security Regolith Explorer (OSIRIS-REx) will journey into space in 2016, scoop up a bit of dirt from the Apollo asteroid (101955) 1999 RQ36, and return it to Earth by 2023 for further investigation.

What lies inside



Asteroid Vesta
Vesta, the second-most-massive asteroid in the Solar System, stands in a class of its own called V-type asteroids. They tend to contain more pyroxene than S-type asteroids.

Core
Data from the Dawn mission showed that Vesta has a core of 110km (68mi) in radius. The core is mostly made up of iron.

Crust of Vesta
Vesta melted at some point early in its history, producing a 'differentiated' core and a basaltic crust.

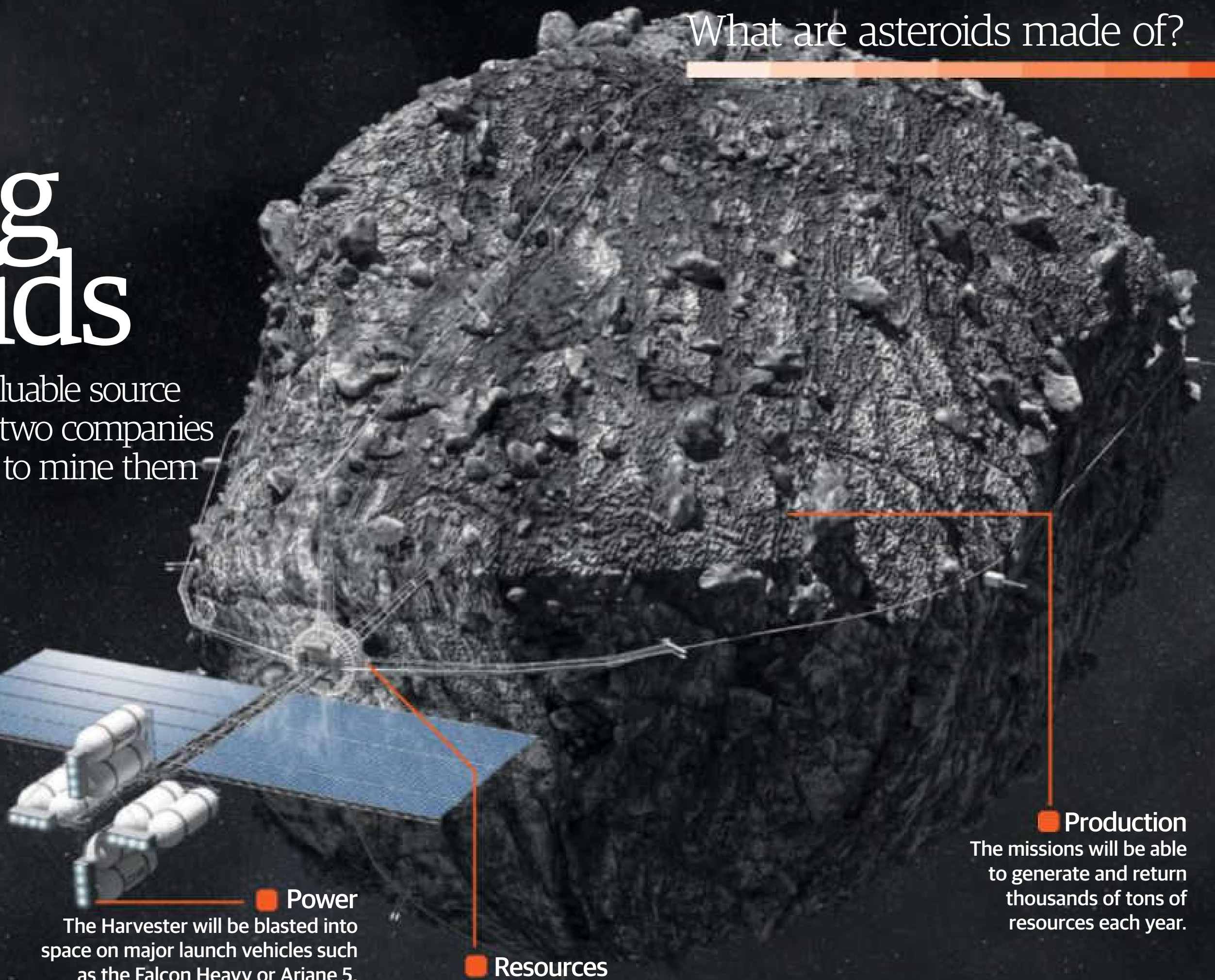
Mantle
Vesta's mantle, wedged between the core and crust, likely includes olivine and diogenite.

Mining asteroids

Asteroids could be a valuable source of resources and so far two companies have announced plans to mine them

Deep Space Industries

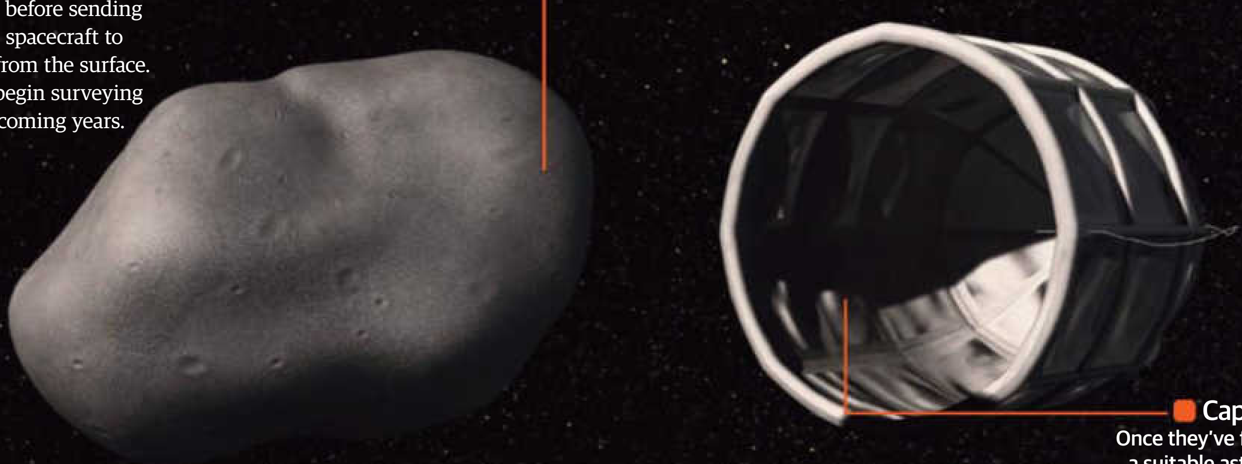
Deep Space Industries plans - at some point - to send robotic probes on a one-way reconnaissance mission to potential asteroid mining sites. Later, larger DragonFly spacecraft would potentially pick up samples or small asteroids for further evaluation on Earth.



Deep Space Industries plans to use its Harvester to mine vital resources from asteroids

Planetary Resources

Planetary Resources first plans to scope out potential asteroids using a telescope. They will then capture a suitable asteroid and reposition it in a stable orbit near Earth, before sending a fleet of robotic spacecraft to return samples from the surface. They expect to begin surveying asteroids in the coming years.



5 AMAZING FACTS ABOUT Moon dust

Astronaut Harrison Schmitt scoops samples of lunar dust and rock during the Apollo 17 mission to the Moon in 1972

1 You shouldn't breathe it

Following a lunar walk, astronaut Harrison Schmitt noted the smell of Moon dust in the air, like gunpowder. NASA pathologist Russell Kerschmann warned that prolonged exposure to Moon dust could seriously damage human lungs.

2 It's magnetic

Because tiny specks of iron are present in the glass shell of each lunar dust particle, magnets can be used to filter the dust out of the air and off sensitive equipment. The dust that makes up lunar soil can also be quickly microwaved into flat sheets, meaning roads and landing pads can easily be created for future missions.

3 It wears through spacesuits

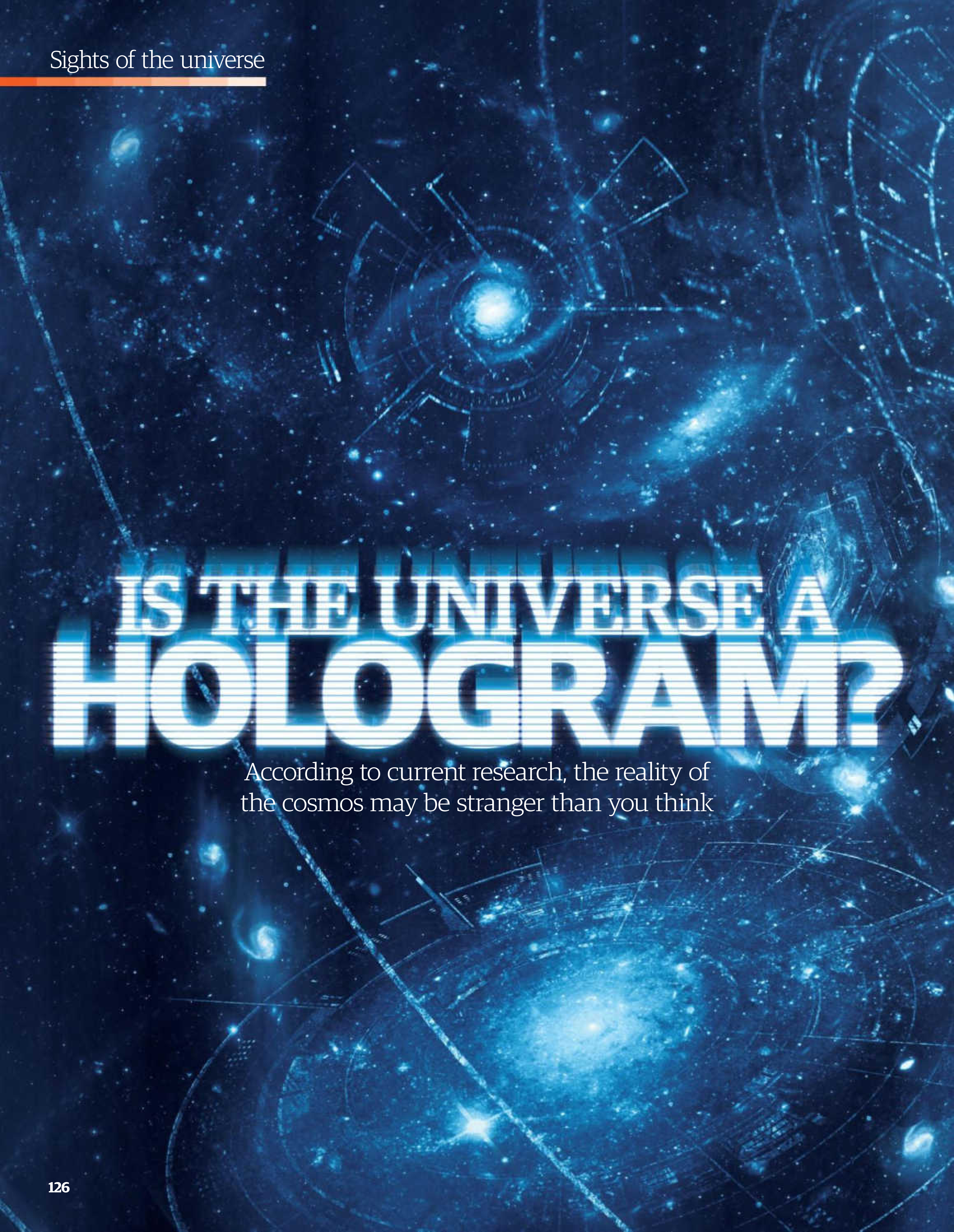
Moon dust is very abrasive and clingy. Apollo 17 astronauts had problems moving their arms properly because lunar dust had clogged up the joints, while it wore through three layers of Kevlar-like armour on Harrison Schmitt's Moon boot.

4 It's actually mostly glass

Lunar dust is mostly made up of very fine particles of silicon dioxide glass, plus iron, calcium and magnesium, as well as other trace minerals. It's all been shattered and ground into a fine powder over billions of years of meteorite impacts.

5 Astronauts have tasted it

In the interests of science (as well as pure human curiosity), Apollo astronauts have touched, smelled and even tasted Moon dust. Apparently, it's as fine as flour but abrasive, plus it both smells and tastes like gunpowder. It's also clingy and hard to brush off.



IS THE UNIVERSE A HOLOGRAM?

According to current research, the reality of the cosmos may be stranger than you think


Hawking's first encountered the information paradox when he applied both quantum physics and general relativity to black holes

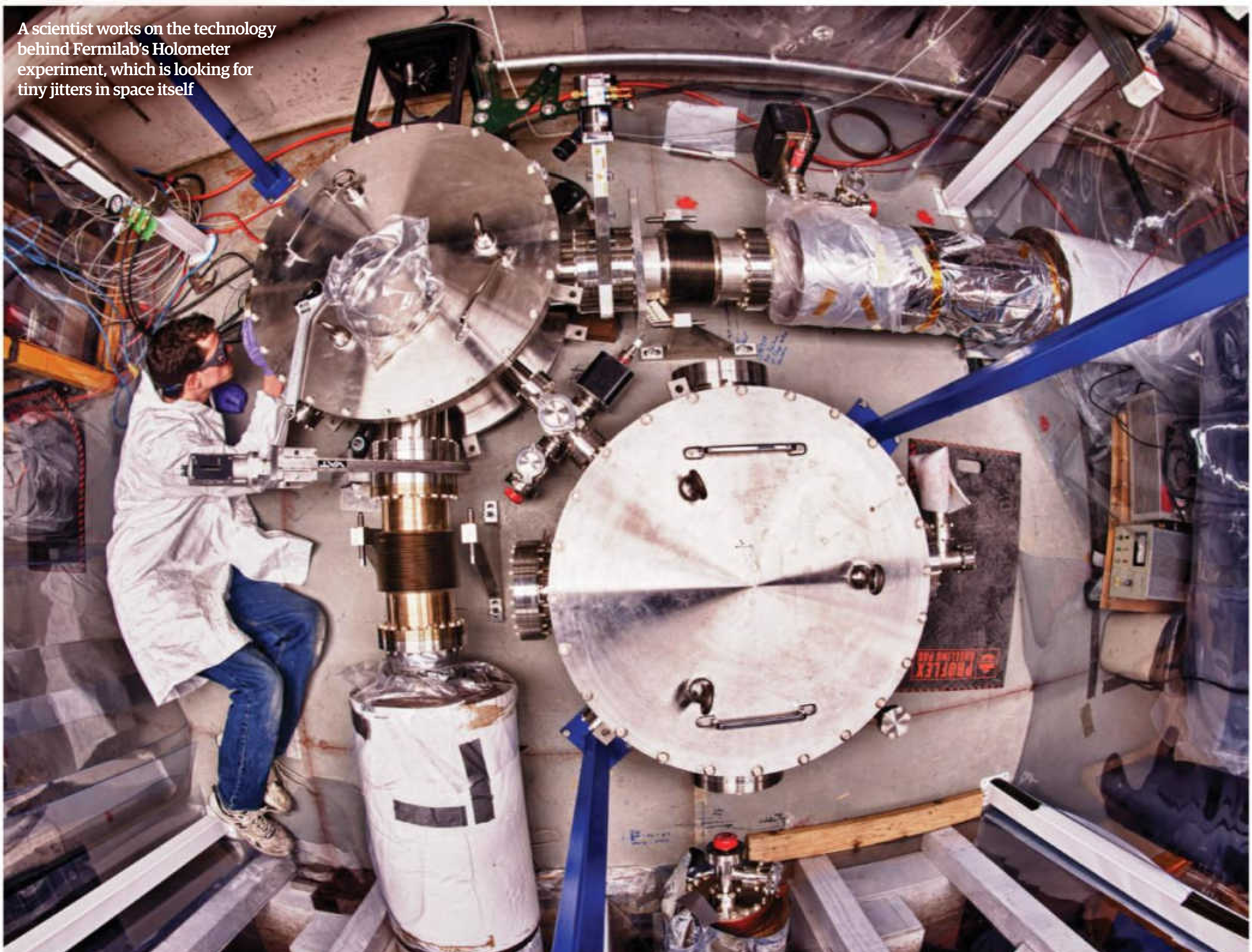
Picture a room filled with books. Then imagine that all the books suddenly disappear. All the information they contained would be lost, right? All the plot lines, characters and happy endings would vanish into thin air. But this library is different. Here, all the information inside the room is also encoded on the floor, the walls and the ceiling. Even though the books themselves are gone, you can still retrieve all of the details they contained by looking at the surfaces that once enclosed them. Want to know how that cliffhanger was resolved? Read the wallpaper. Whodunnit? Consult the carpet. Sounds downright weird, doesn't it?

Our imaginary library gets stranger though. If the books disappeared, but the information in them didn't, did the books even exist at all? Or were they just a projection of the information on the walls, carpet and ceiling? After all, holograms like the ones found on credit cards work in a similar fashion. Viewed in one way they look three dimensional, but all the information they contain is actually encoded in only two dimensions. It is the same information presented differently.

The remarkable thing is that there is growing evidence our universe behaves just like this bizarre library, and that everything we see within it might just be a holographic projection of information encoded on some far distant boundary. "Even gravity might be an illusion," says Daniel Grumiller, from the Vienna University of Technology in Austria.

As with many of the universe's greatest mysteries, this one starts with black holes. A black hole is what you get when a really big star dies. At the end of its life, the star's dense iron core collapses and rips a hole in space into which nearby objects irretrievably fall. These extreme objects are at the centre of

> "Even gravity might be an illusion"
> **Daniel Grumiller, Vienna University of Technology**

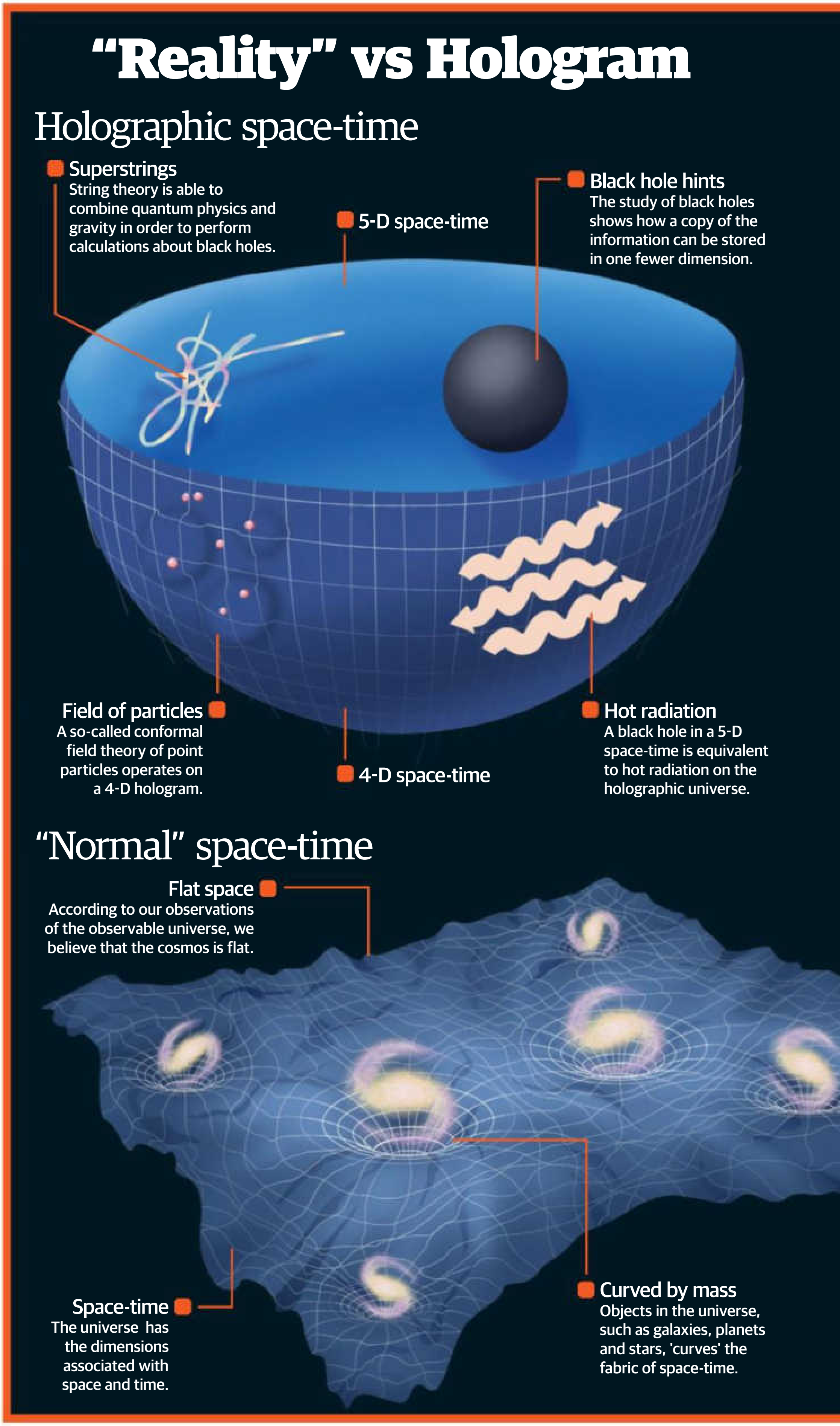

A scientist works on the technology behind Fermilab's Holometer experiment, which is looking for tiny jitters in space itself

physics' ultimate quest: to unite the theories of quantum physics and general relativity. The former is our best description of atoms and the very small; the latter our most successful explanation of gravity and the very big. However, Stephen Hawking's applied both quantum physics and general relativity to black holes in the 1970s and suggested that if both theories were right then information is destroyed inside black holes. This so called "black hole information paradox" is something many physicists just can't accept. The reason the idea is so abhorrent is that it goes against a fundamental principle of quantum physics called determinism. It says that if you have a complete set of information about an object at a given time, you should be able to work out what it was up to before. However, if that information is destroyed then this it is no longer possible.

Imagine that you set fire to a page in a book. The information it contained would not be entirely destroyed. While it would be insanely impractical to do so, in theory, you could collect all of the ashes and retrieve the original information written on the page because, to a physicist's eyes, that original information hasn't vanished from the universe. "It would be nearly impossible to get back in any practical sense, but provided you traced all the ash particles you could do it, at least in principle," says Grumiller. There's still a way you can reconstruct the system's earlier state from its present state. Yet Hawking's initial conclusion from applying quantum physics and general relativity to black holes was that information about matter falling in is destroyed – it is impossible to ever get it back.

Then physicists came up with a way to potentially spare their blushes. They realised that, just like our library, a copy of all the information about the objects inside a black hole might also be encoded on its two dimensional perimeter (known as the 'event horizon'). "We call this idea the holographic principle," says Grumiller. There are some problems with this idea, however, and physicists are frantically still trying to sort out the details. Perhaps the biggest stumbling block is the so-called "Firewall Paradox", a theory that says that information isn't lost if it is left imprinted on the event horizon – a black hole's point of no return.

But why stop at black holes? If every three-dimensional object inside a black hole can be equivalently described by information on an external two-dimensional surface, why can't the same be true of the universe as a whole? Perhaps what we perceive as our three-dimensional existence is merely a projection of information residing on some distant two-dimensional surface, just like the books were a projection of information that was actually on the walls and ceiling of the library. For some, this is a very powerful idea, one that might lead to a successful theory of quantum gravity. The theory of quantum gravity is so sought after amongst physicists because it would be able to explain the very small and the very big at the same time – a one-size-fits-all description of the entire universe. The big issue with uniting quantum physics and general relativity into one coherent theory is that they seem like pieces from two very different puzzles – they refuse to neatly fit together to create a whole. For decades, physicists have been working on ways to



get them to play nice, with string theory a leading contender. This idea basically says that subatomic particles – those that in turn build atoms – are actually made up of tiny vibrating strings. Just as you can play strings on a musical instrument in different ways to produce different notes, so different particles are formed by these strings vibrating in different ways. The trouble is that this theory can only join the puzzle pieces together if the universe has substantially more dimensions than we, as humans, experience. To reconcile that with what we see around us, these additional dimensions are – rather conveniently – said to be curled up really small and so remain out of sight.

But back in 1997, the theoretical physicist Juan Maldacena made quite a breakthrough. He invoked the holographic principle, proposing that the messy world of string theory might just be a projection of a much simpler reality. If string theory is the hologram, we should be looking for the equivalent rules in fewer dimensions – the walls instead of the books. Then, rather than inventing multiple unseen dimensions to get quantum gravity to work, we could accept that one of the dimensions we experience is an illusion. "Some aspects of quantum gravity are much easier to calculate using this alternative picture," says Grumiller.

It took until 2013 for these rules to be found. A team of Japanese physicists led by Yoshifumi Hyakutake calculated some properties of a black hole using string theory with all its extra dimensions. They then did the same calculation using quantum physics, but in one fewer spatial dimension than we're used to. Remarkably, the two sets of calculations matched. So their work says that string theory is equivalent to quantum physics, albeit in fewer dimensions. Perhaps what we perceive as the universe is just a hologram based on the rules of quantum physics playing out on some distant surface with one fewer dimension. As the latter makes no mention of gravity, this implies that the force of gravity is part of the hologram. Although Grumiller notes that, "if you run over the edge of a cliff you'll still fall down."

However, as is often the case, there is a catch. Both Maldacena and Hyakutake's team performed their calculations in a hypothetical universe in which the overall shape of space does not match our own. Cosmologists believe that our local universe is flat. That is to say it has no overall curvature and the angles of a triangle drawn between three points add up to 180 degrees just as on a sheet of paper. But both Maldacena and Hyakutake's work was based on a universe with "negative curvature" as the calculations were easier to solve. Such universes are saddle shaped and triangles drawn on its surface have angles adding up to less than 180 degrees.

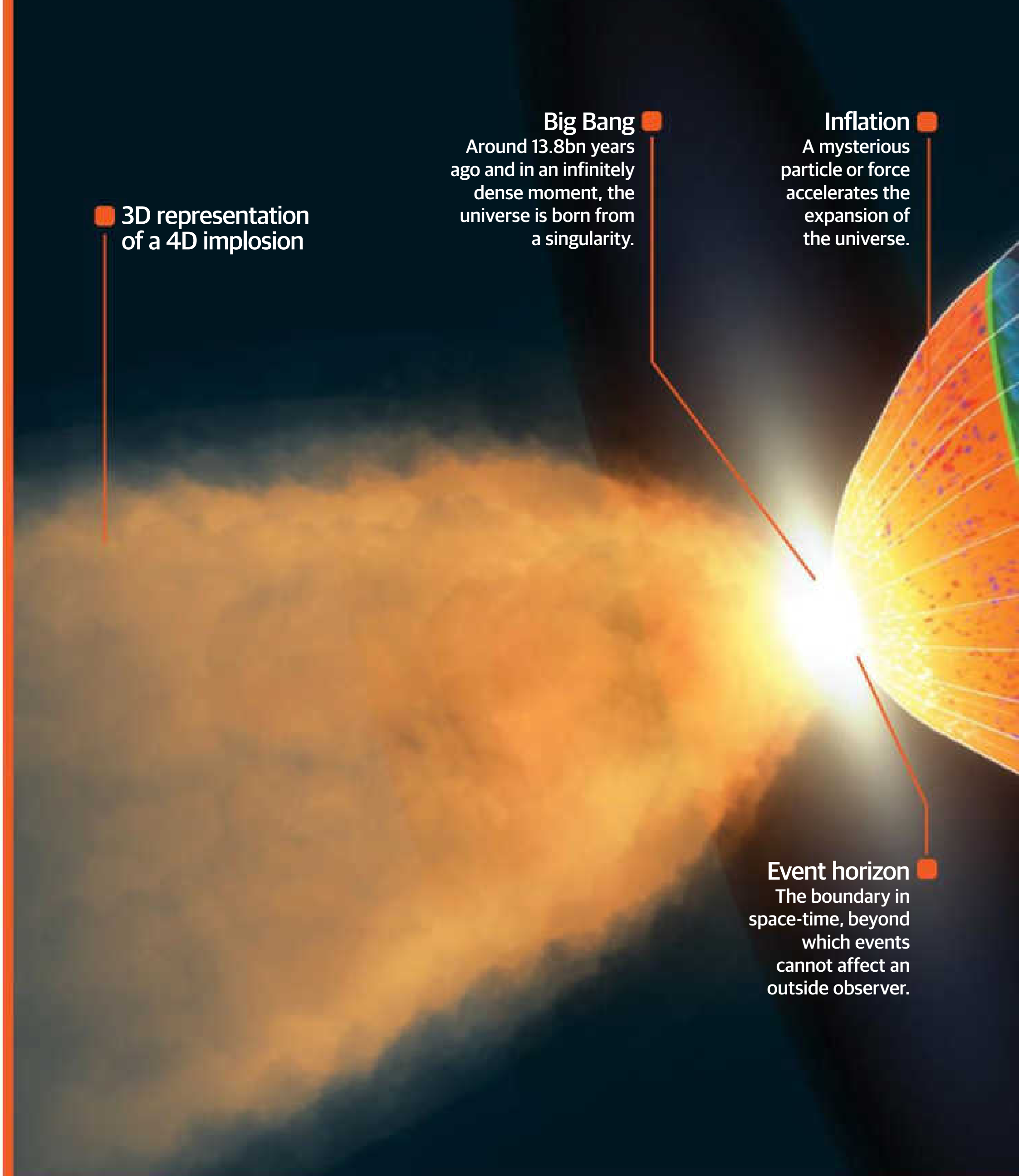
For the holographic principle to be taken seriously, it would have to be shown to apply to flat universes too. Inspired by this problem, Daniel Grumiller and colleagues spent three years trying to get it to work and they announced their findings in early 2015. "We found that the holographic principle can indeed be applied to flat space, too," he says. Suddenly the idea of our three-dimensional experience of the universe being a hologram was back on the table. So, as things stand, the case for the holographic principle is on

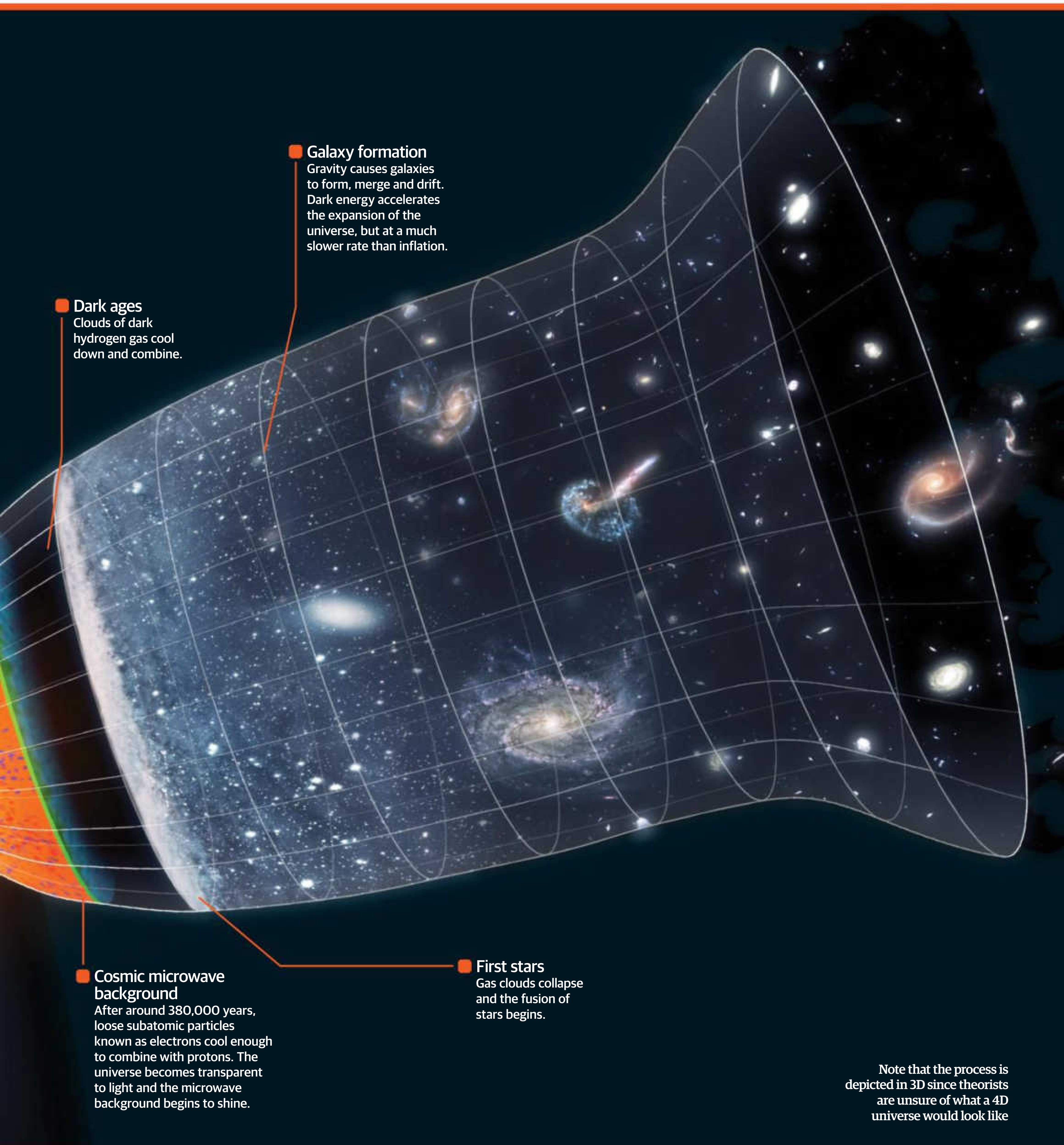
How a holographic universe is made

Things would have taken an unexpected turn after the Big Bang

It's widely thought that the Big Bang – the event which created the universe – began with an infinitely dense point known as a singularity.

Singularities are thought to be unpredictable, with the laws of physics breaking down. Some proponents of the holographic universe postulate that the universe began when a star in a four-dimensional universe collapsed to form a black hole. In this case, the universe would be protected from the singularity at the heart of the black hole thanks to a three-dimensional event horizon.

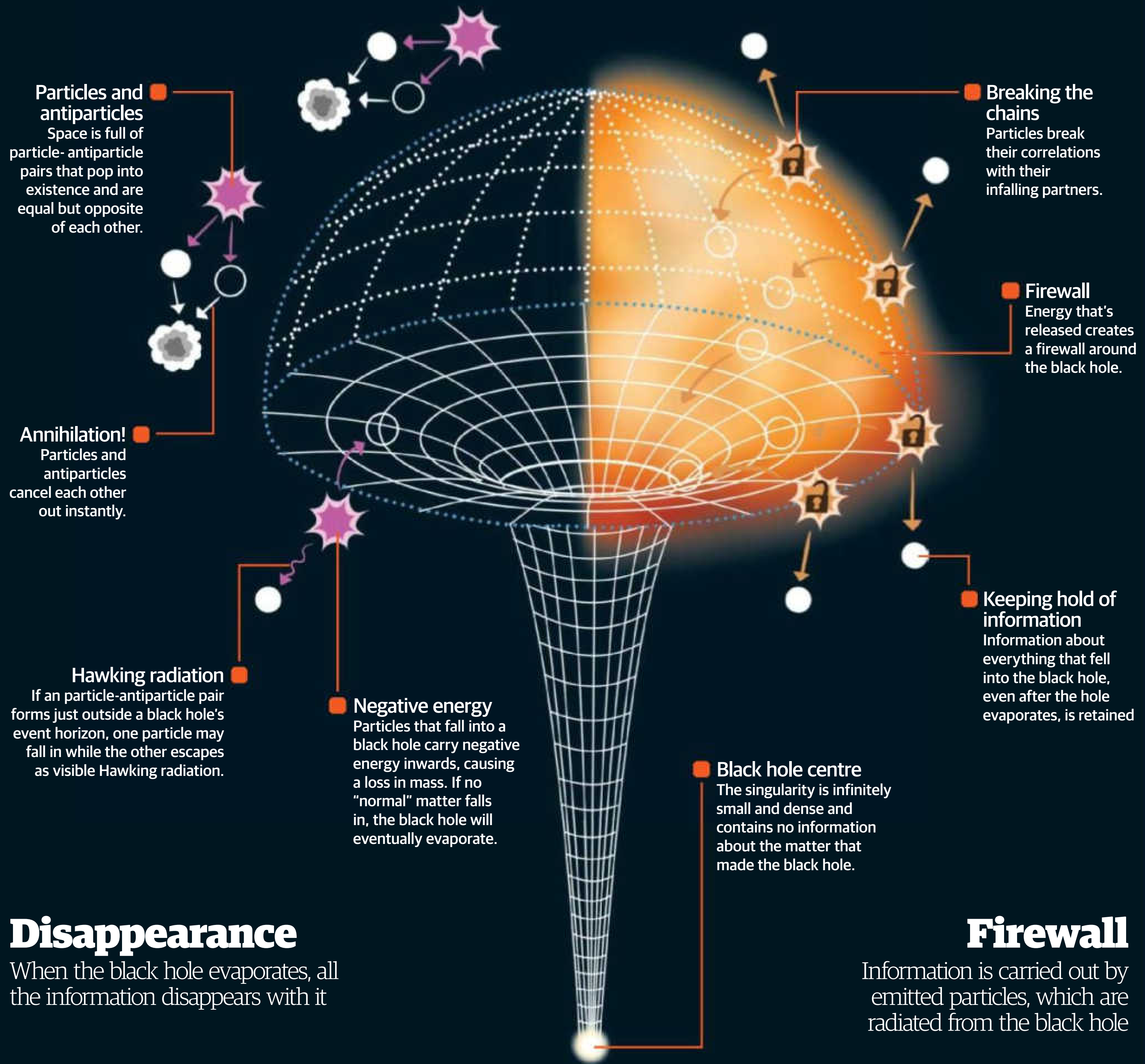


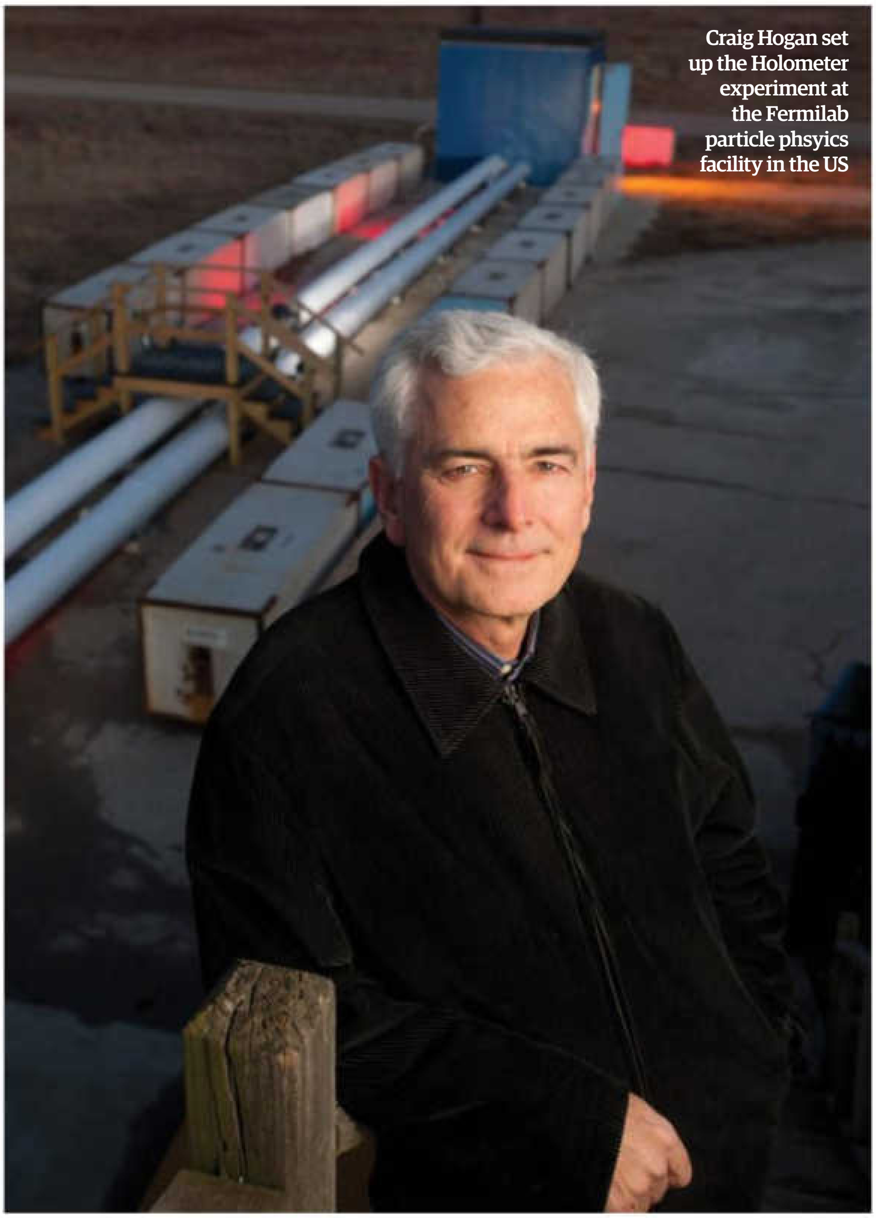

Galaxy formation
Gravity causes galaxies to form, merge and drift. Dark energy accelerates the expansion of the universe, but at a much slower rate than inflation.
Dark ages
Clouds of dark hydrogen gas cool down and combine.
Cosmic microwave background
After around 380,000 years, loose subatomic particles known as electrons cool enough to combine with protons. The universe becomes transparent to light and the microwave background begins to shine.
First stars
Gas clouds collapse and the fusion of stars begins.
Note that the process is depicted in 3D since theorists are unsure of what a 4D universe would look like

The Firewall Paradox

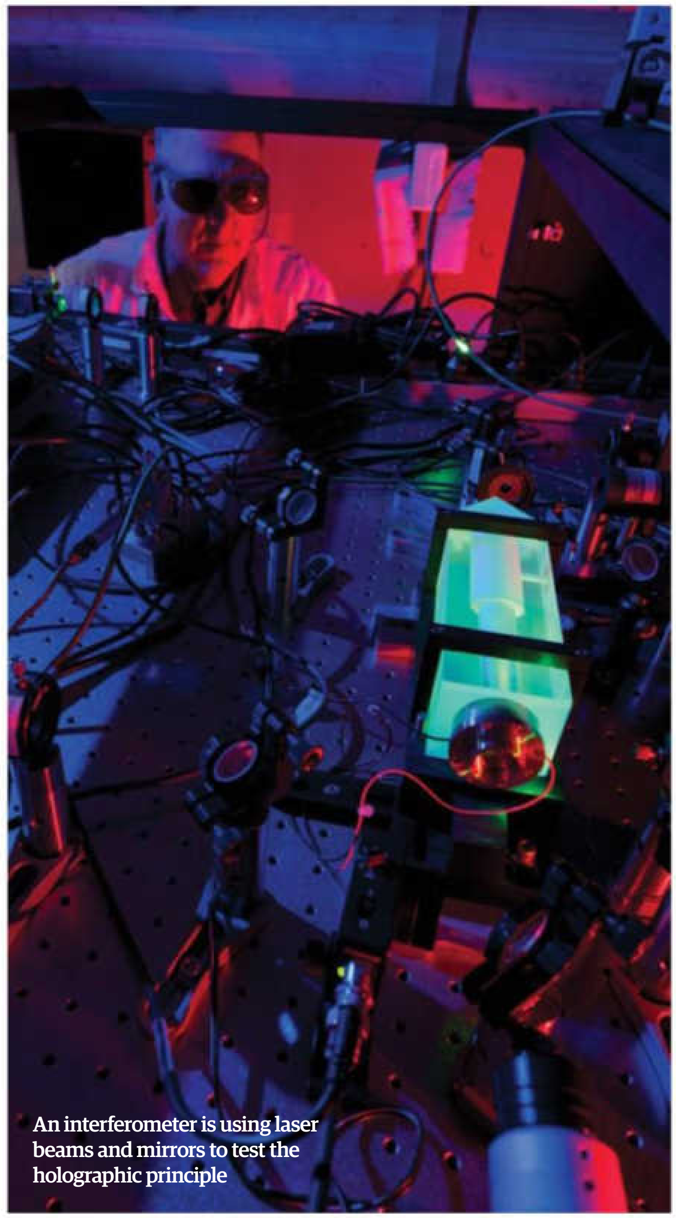
How black holes could hint at a holographic universe

Physicists get around the problem of information being lost if a copy of that data is left imprinted on the event horizon. In quantum physics, two copies of the same information technically shouldn't exist. However, you can dodge that bullet by saying that a person inside the black hole can't see the information on the event horizon and a person outside the event horizon can't see the information inside it. Complications then arise due to black hole evaporation, predicted by Stephen Hawking. Once roughly half the black hole has evaporated, there is no longer enough data on the edge of the black hole to match the information inside it. General relativity predicts that anyone passing through the event horizon would hit a "firewall" and be burnt to a crisp. This goes against the normal prediction of general relativity that says you shouldn't notice anything different when passing this imaginary line, but you would certainly notice getting fried!





Craig Hogan set up the Holometer experiment at the Fermilab particle phsyics facility in the US



An interferometer is using laser beams and mirrors to test the holographic principle

“The messy world of string theory might just be a projection of a much simpler reality”

a firm theoretical basis. It seems, at least on paper, that we can explain everything we see around us in fewer dimensions than are apparent. But that's only half the battle. Like any scientific theory, it needs experimental proof to back it up. The theory needs to make a prediction that researchers can go out and successfully test.

Such a prediction is currently being tested by Craig Hogan with his “Holometer” experiment at the Fermilab particle physics facility in the US. If the universe can be explained purely in quantum physics terms, then all the rules you'd normally associate with the theory don't just apply to atoms, but also to space itself. The quantum realm is notoriously counter-intuitive. It is possible for a subatomic particle to be in two places at once simultaneously. Similarly, you can never pin down the precise location of an atom – you can only assign probabilities to where it is most likely to be found. “The holographic principle is telling us that this uncertainty should also apply to the fabric of space,” says Hogan. This means that, on the smallest scales, space itself should be blurry. Picture it like a photograph. Seen on a computer screen the photo looks continuous. But zoom in enough and you see it is actually made of discrete chunks – its constituent pixels. On the smallest scales, the photograph is actually blurry. The same could be true of space.

Hogan set up the Holometer experiment to test this idea. His equipment is what physicists call an interferometer. Laser beams are bounced off mirrors along two equal paths – or “arms” – that are at right angles to each other. The laser beams then meet in the middle and a detector picks up this combined beam. But the laser beams only combine perfectly if they take exactly the same time to travel along each arm. If one is delayed along the way then it will lag behind the other and they won't join up properly. “If the holographic principle holds then the quantum uncertainty associated with space should cause ‘jitters’ in the experiment,” says Hogan. These jitters would cause a delay of around 10^{-25} seconds in the arrival time of one of the beams. That's just one ten trillionth of a trillionth of a second.

The bad news is that Hogan's experiment ran for 140 hours and found no such jitters. “But it's not over,” Hogan says. “We've only ruled out one particular type of blurriness.” Undeterred, he has reconfigured the experiment to look for evidence of a slightly different version of the holographic principle. So, the quest to find out whether what we see around us – including gravity itself – is an illusion continues. But if experiments like Hogan's are successful, we might have to completely re-evaluate everything we thought we knew.

Into deep space

Take a look at what lies outside the comforts of the Milky Way

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Sombrero Galaxy

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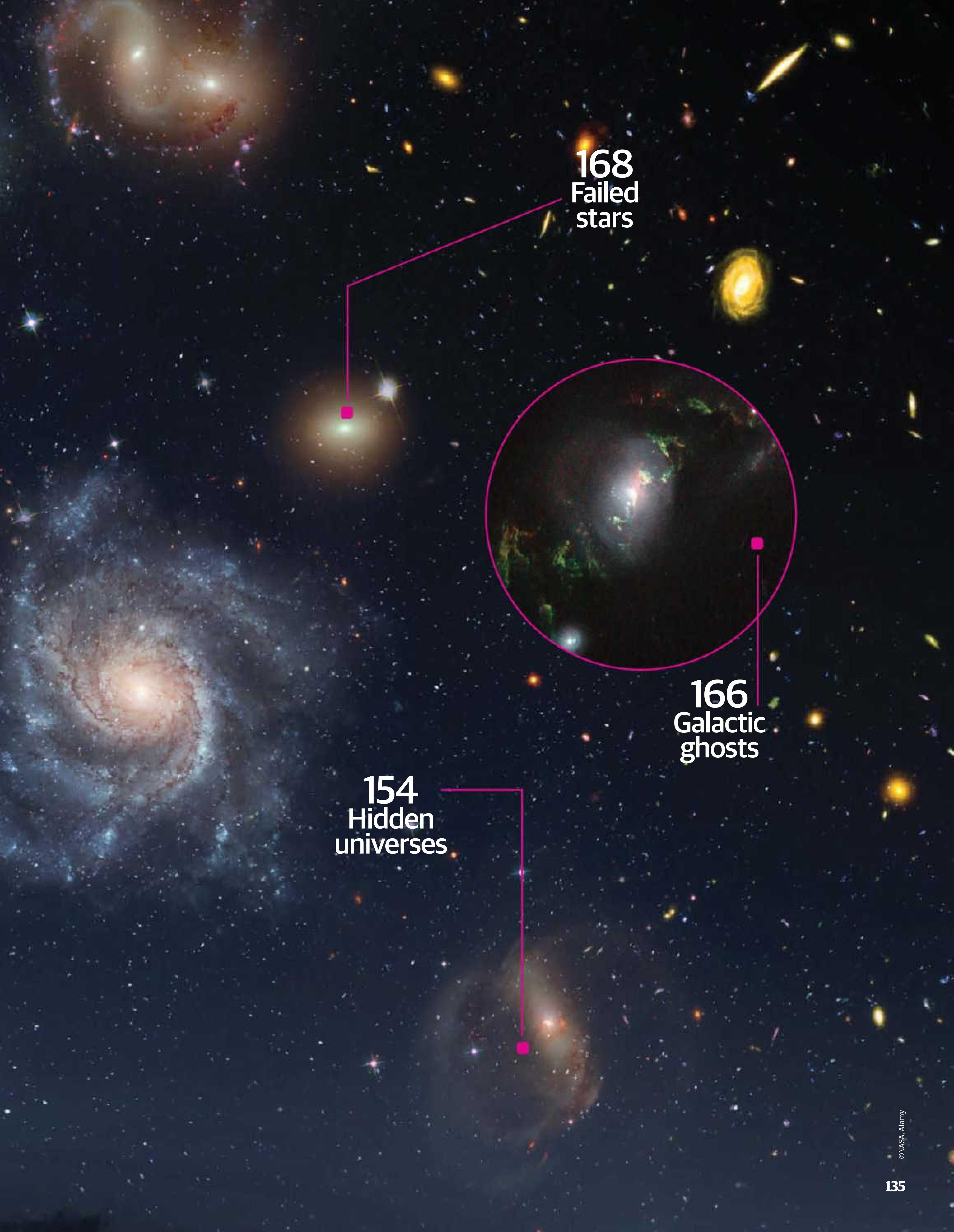
Supernovas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All About Space take a look at some of the Sun's strangest stellar cousins

FROZEN STELLAR GIANT

+10 of the weirdest stars in the galaxy

Aside from the fact that the Sun is orbited by the only planet in the universe known to be home to life - which, let's face it, is pretty special - our star is pretty normal as far as stars go.

Along with 90 per cent of the other stars in the universe, it is classed as 'main sequence': powered by fusing hydrogen to make helium. It is medium sized, it is using up its fuel relatively slowly, and it will die quite quietly; without all the drama of a supernova and with no risk of leaving behind a black hole. However, some of the other stars out there are seriously strange. In the Milky Way and its surrounding satellite galaxies, astronomers have uncovered some weird and wonderful things. There are stars shrouded in clouds of lead, stars spinning so quickly that they are almost pulling themselves apart, and stars that are being eaten by their companions. And those are just the ones that we can see.

Scientists have also hypothesised about the existence of even weirder objects, including stars physically inside other stars, and stars orbited by alien megastructures. **All About Space** explores some of the weird and wonderful stars in the galaxy.

1 The star that defies all logic

Wolf-Rayet stars usually throw out gas but NaSt1 behaves very differently by allowing its outer layers to be stolen

Nasty 1 (officially known as NaSt1) is a Wolf-Rayet star, which is many times the mass of our own Sun, and it is burning through its fuel at an astonishing rate. It has been photographed by the Hubble Space Telescope and the Chandra X-Ray Observatory, and although there are other stars of the same type, none are quite like this one.

Wolf-Rayet stars are huge, rapidly evolving stars that quickly lose their outer layers of hydrogen gas, exposing the hydrogen core beneath. They produce steady streams of solar wind and occasionally eject large quantities of material, blowing their own fuel supply out into space. Other Wolf-Rayet stars spit gas from their poles in two enormous lobes, but Nasty 1 is surrounded by a clumpy, 3.2 trillion kilometre-wide (two trillion mile-wide) disc. It seems that rather than losing all of its gas by throwing it away, Nasty 1 has actually had its outer layers stolen.

The Chandra Observatory has detected evidence of another star in the area and this hidden companion is thought to be the culprit. It is thought that when Nasty 1 expanded as it started to run out of fuel, the neighbouring star could have stripped the outer layers of gas away.

Nasty 1 is racing through its life cycle and evolving at an astonishing rate

An artist's impression of a brown dwarf surrounded by a disc of dust and gas

2 Frozen stellar giant

The term 'frozen star' was once used by Russian scientists to describe black holes (to an outside observer, objects crossing over the event horizon appear to freeze), but there are thought to be stars that are literally frozen.

Stars release energy using nuclear fusion; smashing atoms together until their nuclei fuse, forming heavier elements in the process. The first stars in the universe were fuelled by the lightest elements - hydrogen and helium - but as the second and third generations of stars were born, these newly made heavier elements were incorporated into the gas.

In 1997, astrophysicists Fred Adams and Gregory Laughlin from the University of Michigan predicted that as the universe gets older, the stars within it will continue to become increasingly metallic; including ever increasing proportions of heavy elements. The cores of these future stars will radiate less energy, which could allow them to sustain hydrogen fusion at much lower masses.

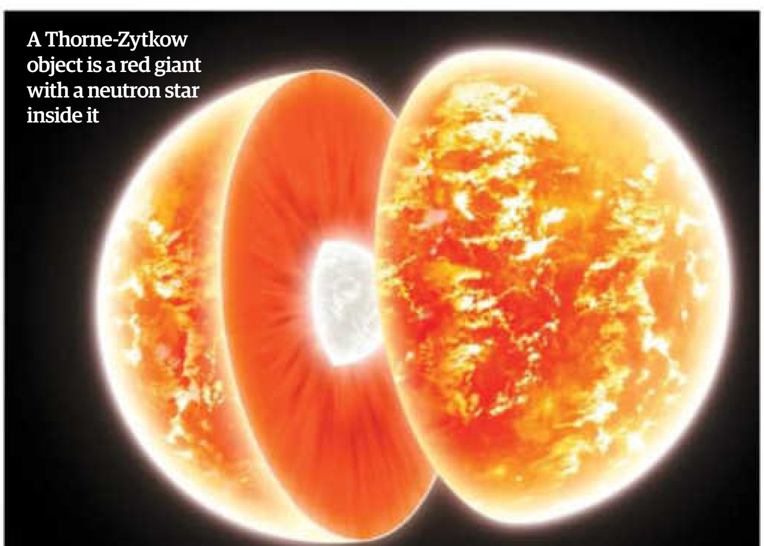
The rate of the fusion inside these small metallic stars would be so slow that the energy released would be barely sufficient to heat the surface to 0 degrees Celsius (32 degrees Fahrenheit) - the freezing point of water. So, these dim and long-lived stars could even be surrounded by huge clouds of ice.

3 Stars that live inside others

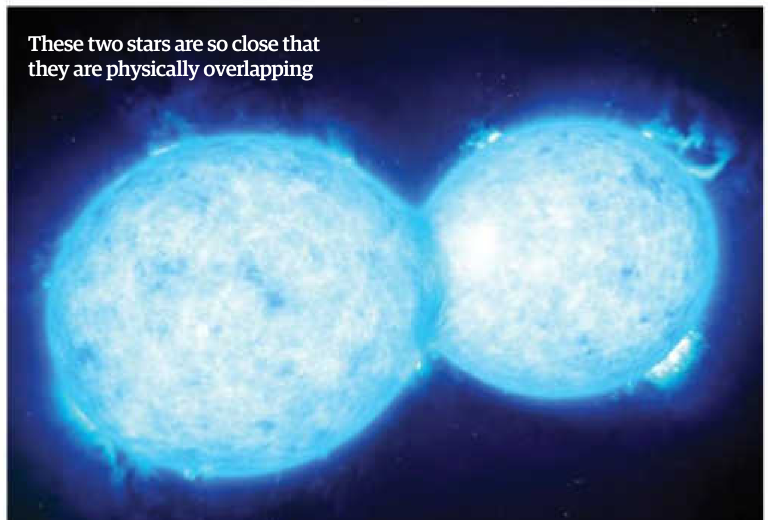
We know that some stars are close enough to touch, but it is possible that some star pairs have gone one step further. In the 1970s, astrophysicists Kip Thorne and Anna Zytkow hypothesised that if a neutron star were close enough to a red giant, one could end up inside the other.

When massive stars die, they collapse in a dramatic explosion known as a supernova. In the process, their remains crunch down to form a black hole or a dense neutron star. Smaller stars become red giants when they start to run out of fuel, swelling to many times their original size before they die. If a neutron star is too close to a red giant, the pair could end up touching. As they carried on orbiting they would rub together, gradually spiralling inwards until the neutron star was fully enveloped. Eventually, Thorne and Zytkow reasoned that the neutron star could replace the red giant's core.

In 2014, Zytkow, and her collaborators in Arizona and La Serena, spotted a star with an unusual emission pattern. She and Thorne had originally predicted that stars inside stars would have a burning shell with unusual quantities of specific elements, and this star, HV 2112, has excess rubidium, lithium and molybdenum in its atmosphere, making it a possible candidate.



A Thorne-Zytkow object is a red giant with a neutron star inside it



These two stars are so close that they are physically overlapping

4 Stars so close that they touch

It is estimated that half of our closest stellar neighbours are actually binaries, sharing a common centre of gravity with one or more other stars. Most pairs remain completely separate, orbiting at such a distance that they never cross paths, but others get so close that they touch.

In a star-forming region of the Tarantula Nebula, a pair of massive stars are orbiting a common centre of mass at a distance of just 12 million kilometres (7.5 million miles) - that's more than three-times closer than Earth is to Venus - with their centres so close together, their atmospheres overlap. Together, the pair of stars are more than 50-times larger than the Sun, and they complete an orbit almost once a day. They are both a similar size, and rather than stealing gasses from one another, they are sharing about a third of their atmospheres.

The future for the system is uncertain, but with the stars rubbing together there is a chance that they will eventually merge. The resulting star would be truly massive and would spin rapidly on its axis. When the star eventually died, it would go out with a monstrous explosion.

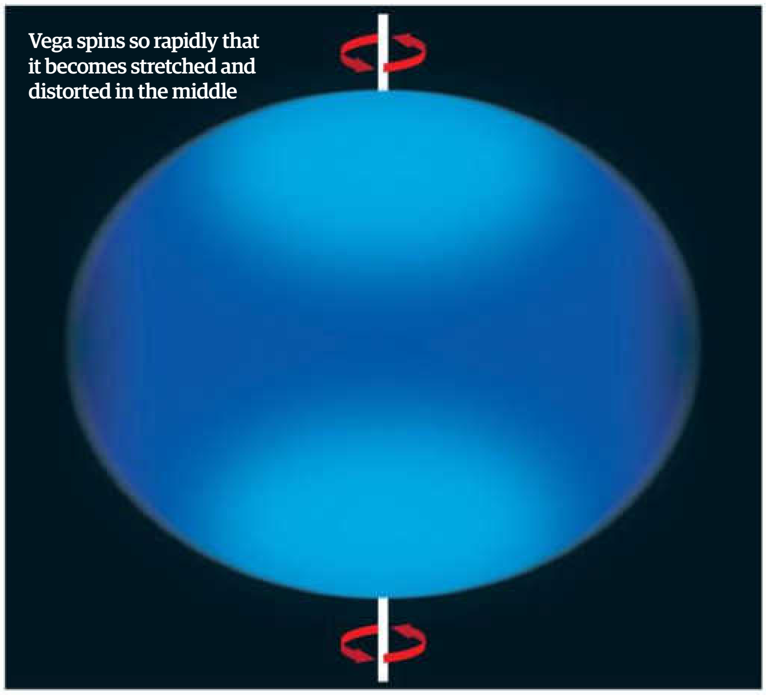
Alternatively, the pair of stars might manage to remain separate, ending their lives as two adjacent black holes.

5 Egg-shaped stars

The Sun is almost spherical but, like clay on a potter's wheel, the faster they spin, the more distorted their shape becomes. Two well-known examples of rapidly spinning, egg-shaped stars are Regulus, in the constellation Leo, and Vega, in the constellation Lyra.

The Sun completes a rotation on its axis around once every 27 days, but Vega spins a full turn in just 12.5 hours. In fact, it is rotating at 90 per cent of the estimated maximum speed that it could manage before ripping itself to shreds. The result of this rapid spin is that the star is stretched outwards at the equator, bulging out to become more than 30 per cent wider than the star is tall.

Why some stars rotate dangerously close to their maximum speed is not fully understood, but some stars have a companion that could be the culprit. Regulus is part of a binary system, and its companion star could be increasing its spin speed by spraying matter onto its surface; a bit like spraying a ball with a water pistol. Vega, on the other hand, does not seem to have a companion and the reason for its rapid spin is unknown.



Vega spins so rapidly that it becomes stretched and distorted in the middle

7 The star with the odd flicker

The idea that there might be intelligent life out there in the universe is still hotly contested, but scientists occasionally spot things in space that might point to alien civilisations. And, recently, NASA's Kepler Space Telescope has been recording something strange.

A bright star 1,400 light years from Earth keeps dimming dramatically, indicating that something could be temporarily blocking the light. This could be caused by orbiting planets, but in this case the change in intensity seems too great.

The identity of the structure orbiting KIC 8462852 is a mystery, but some have suggested that it could be caused by a megastructure built by intelligent aliens. It might sound far-fetched, but the Search for Extraterrestrial Intelligence (SETI) institute have taken the findings seriously enough to turn their Allen Telescope Array towards the star.

So far, though, they haven't detected any signals and SETI Institute astronomer, Seth Shostak, urged caution: "The history of astronomy tells us that every time we thought we had found a phenomenon due to the activities of extraterrestrials, we were wrong."

But they haven't given up hope just yet, and the search for alien life will continue next year using the upgraded Green Bank Telescope in West Virginia.

6 Impossible stellar object

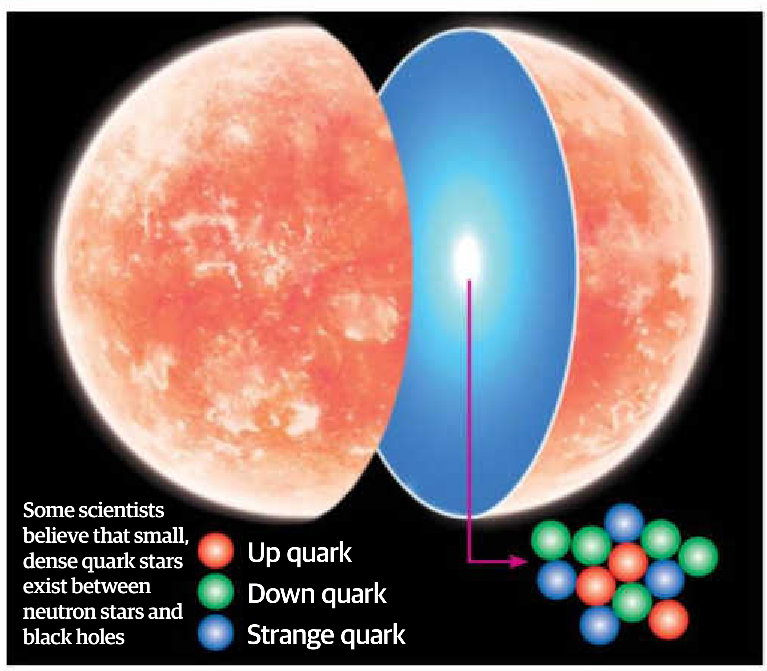
The force of gravity is constantly urging stars to collapse but nuclear fusion within the star provides enough pressure to prevent this from happening. However, when a star runs out of fuel the result is inevitable: the star will collapse.

In the most extreme circumstances, the collapse is total and the star crunches down into a black hole, but for less massive stars, the collapse stops early. Atoms are crushed together until protons and electrons fuse to form neutrons, and the result is a dense neutron star. But some scientists believe that the sequence does not stop there.

Neutrons are made up of even smaller particles called quarks, and it is possible that there could be another stage in between neutron stars and black holes; smaller, denser and compact quark stars.

In 2002, NASA's Chandra X-ray Observatory spotted a candidate – a strange looking neutron star, which appeared too small, as though its matter had crunched into a smaller space than expected. Later, in 2008, a team of Canadian scientists from the University of Calgary reported three unusually bright supernovae, which they suggested could be the result of a 'quark nova'; a burst of energy released as a neutron star collapses to form a quark star.

Though quark stars are still a hypothetical concept, they hint at the possibility of other unusual objects existing between neutron stars and black holes – including one of our next entries, the electroweak star.



Some scientists believe that small, dense quark stars exist between neutron stars and black holes

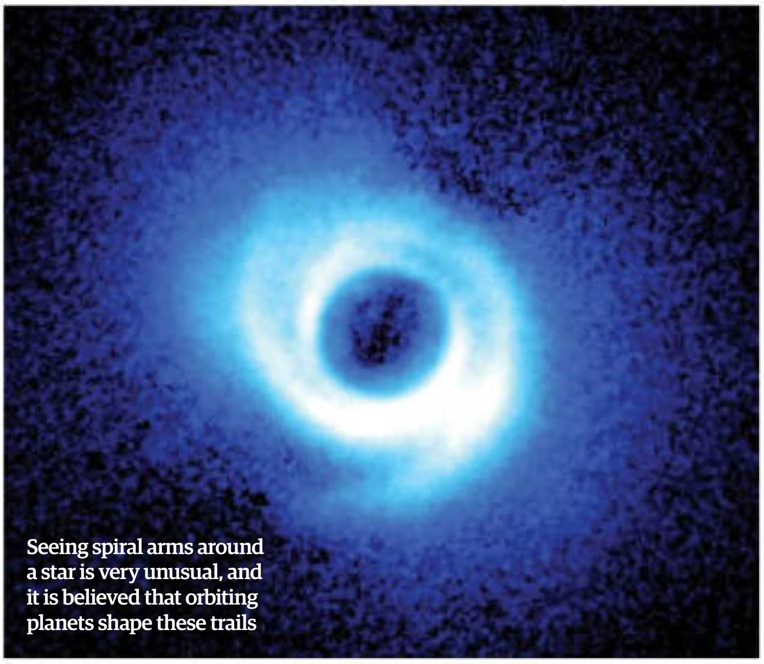
It has been suggested that the dimming of light from KIC 8462852 could be caused by a cloud of comets

8 The star that's like a galaxy

In 2011, NASA announced that researchers using the Subaru Telescope in Hawaii had spotted a young star surrounded by a spiralled disc of dust and gas. Spiral arms are nothing new, they are a feature commonly seen in galaxies, but to find them around a star was completely unexpected and never seen before.

Considering the amount of time humans have been staring at the sky, this was a special find, as NASA explained: "For more than 400 years, astronomers have used telescopes to study the great variety of stars in our galaxy. Millions of distant suns have been catalogued."

Since this first discovery, other stars with spiral arms have now been identified, including MWC 758, which has two distinct arms. These distinctive trails are made from the remains of the dust and gas that originally formed the star, and it is believed that orbiting planets shape these trails. Around other stars, planets have left rings and holes in the gas and dust. Computer modelling suggests the spirals could be formed in a similar way, as large objects orbiting the star interfere with the disc of matter around it. So, the shape of the spirals could hold clues about the location and mass of these planets.



Seeing spiral arms around a star is very unusual, and it is believed that orbiting planets shape these trails

9 Super-exotic star

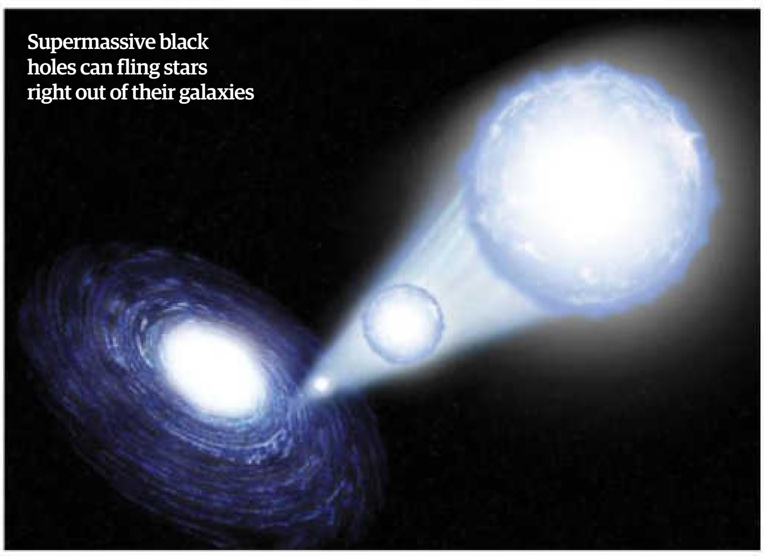
Quark stars are thought to exist somewhere between neutron stars and black holes, but there could be yet another undiscovered type of star in the sequence.

In 2009, it was suggested that quark stars themselves could collapse a little further to form 'electroweak' stars. 'Electroweak' refers to two of the four fundamental forces; the electromagnetic force and the nuclear weak force. The electromagnetic force is the physical interaction between charged particles, and the nuclear weak force is the glue that holds particles together. The idea is that as a quark star continues to collapse towards becoming a black hole, the temperature inside will rise and, at a certain point, the electromagnetic force and nuclear weak force will become virtually indistinguishable.

At this point, the quarks are converted into particles called leptons. This process could release enough energy to delay the complete collapse of the star into a black hole.

Spotting these hypothetical stars, however, will be a challenge. The energy released when quarks are burnt leaves the star as neutrinos. These are similar to electrons but without any electrical charge, and they travel through matter with very little interference, making them really difficult to detect.

Electroweak stars are thought to exist somewhere between neutron stars (pictured) and black holes



Supermassive black holes can fling stars right out of their galaxies

10 The speeding stars

In 2014, scientists at the University of Utah spotted a star moving at speeds in excess of 1.6 million kilometres (one million miles) per hour. Known as a hypervelocity star, it is one of only a handful ever identified. These stars are nomads; something has seriously disturbed their orbit around the galactic centre, and they are on a one-way trip out of the Milky Way.

One explanation – put forward in 1988, before the first hypervelocity star had even been seen – is that these speedy objects have been kicked out by the supermassive black hole at the galactic centre, Sagittarius A*. Around half of the stars in the galaxy are thought to orbit in pairs. When these closely linked systems get too close to the huge gravitational pull of a black hole, one star can be forced into a tight orbit whilst the other is flung out into space. The idea has been around since the 1980s, but it wasn't until 2005 that the first of these hypervelocity stars was actually seen.

Astronomers have now detected more than 20, and it is predicted that there could be many thousands more. There is also a ring of stars in high-speed orbits around the black hole at the galactic centre – potentially the partners of the stars that are now hurtling out of the Milky Way.

11 Stars with clouds of lead

In 2013, scientists from the Armagh Observatory in Northern Ireland spotted two helium-rich subdwarf stars shrouded in vast clouds of lead. The outer temperature of the stars is so hot that the electrons are being stripped away from the lead atoms, creating visible emissions that can be seen from Earth. According to the Royal Astronomical Society, for every 10 billion hydrogen atoms inside the Sun there is less than one atom of lead, but these two new stars have 10,000 times the amount, which can be found in a layer that is estimated to be 100 kilometres (62 miles) thick.

Lead is one of the heaviest elements found in nature and is produced when massive stars explode in violent supernovae. The stars that contain it were formed from the gas ejected by these explosions, but this alone does not explain why there is so much lead in the atmospheres of these stars. Scientists believe these stars are going through a late stage in their life cycle; losing their outer layers and transforming from red giants into smaller, brighter, hot subdwarfs. As they shrink, pressure from the light sorts the star's internal gases into layers, pushing the lead outwards.

It is unusual for stars to contain so much of the heavy element, lead

Behemoth galaxy

At the heart of the giant Perseus cluster lies a monster of a galaxy

It seems appropriate that one of the most massive known objects in the universe, the Perseus galactic cluster, should also be home to a particularly huge galaxy at its centre. The giant elliptical NGC 1275 is 230 million light years away in the constellation of Perseus and actually consists of two galaxies - one a huge elliptical and the other a small spiral - in what's known as a high-velocity system.

These galaxies seem set to collide and are moving towards each other at 3,000 kilometres (1,864 miles) per second. This Hubble Space Telescope image shows filaments of cool, mainly hydrogen gas surrounded by gas measuring up to 55 million degrees Celsius (100 million degrees Fahrenheit) in the cluster, which emits strong X-rays.

The Perseus cluster has recently come under the spotlight of astronomers because it's the source of a particular X-ray signal that couldn't have come from ordinary matter. It's thought that an exotic particle called a sterile neutrino, which is related to dark matter, could be responsible. Study of the Perseus cluster, and other massive objects in the universe like it, is giving scientists a better idea of the nature of dark matter.

Behemoth galaxy

Filaments feed out of the giant elliptical galaxy NGC 1275 in searing-hot, X-ray-emitting gas in the Perseus cluster

STAR QUAKES

Seismic waves unleashed by the violent forces inside stars are revealing once-hidden secrets of stellar interiors

What does a star sound like? It might seem like a strange question, but every star in the sky is generating sound waves, even if we can't hear them across light years of vacuum. What's more, these stellar waves have frequencies much too low for human hearing - periods of minutes to hours, compared to the 20 to 20,000 cycles per second our ears can pick up.

In effect, these sound waves are the same as the seismic waves that are known to cause earthquakes on our own planet. Most earthquakes are triggered in Earth's relatively thin outer crust. In a similar fashion, stellar seismic waves are generated by the churning of huge masses of gas in the upper layers, close to a star's visible surface. Both types of wave ripple out in all directions, passing all the way through either planet or star. These similarities mean that just as geologists can use seismic waves to probe Earth's inner structure, astronomers are now finding that sound waves can reveal the inner secrets of the stars.

Professor Tim Bedding is part of a team at the University of Sydney that has started using this new technique, known as asteroseismology, to study the later stages of stellar evolution. "A star is a huge ball of gas held together by its own gravity," he explains, "and many stars undergo oscillations that involve periodical expansion and contraction. By measuring the periods of these oscillations we can infer conditions deep inside the star, such as temperature and chemical composition."

So how do the waves manifest themselves? "They're rather like the oscillations inside the tube of a flute or trumpet," continues Bedding, "except that a star is three-dimensional, which makes its oscillations more complicated."

When a wind instrument is played, the air column is limited to oscillating in just one dimension, rippling back and forth and the sound waves settle into stable patterns known as modes. "But while an instrument has a limited number of modes, a star like the Sun can oscillate in hundreds or even thousands of different modes simultaneously."

But there's a problem - while the Sun is on our cosmic doorstep and has been studied in detail by 'helioseismologists' since the 1970s, other stars are many millions of times more distant - mere points of light through even the most powerful telescopes. Directly observing ripples on these stars' surfaces is far beyond current technology, but fortunately, as Professor Bedding points out, the waves also produce another effect that we are able to measure: "They affect the light output of the star, causing its brightness to vary in time by small amounts, in a very complicated way."

That's the theory at least, but putting it into practice is another matter: "Measuring those brightness variations from the ground is very difficult due to the effects of the Earth's atmosphere. What we really need is a space telescope that can make regular and very accurate measurements of stellar brightness."

Fortunately in 2009, NASA launched a satellite that provides just this kind of data. The Kepler mission's main aim was to detect planets around distant stars by measuring the tiny regular dips in their brightness when a planet transits across the face of the star. But its highly accurate measurements are also perfect for asteroseismology. "It's created a revolution in the field over the past few years," enthuses Bedding.

By identifying the complex interacting wave modes influencing a star's brightness, and comparing them to computer models of stellar interiors, it's possible to work out the arrangement of layers with different densities inside the star. Perhaps the best example so far comes from the Sydney team's work on red giants – stars near the end of their lives that have swollen to enormous size as they start to run out of fuel.

Stars like the Sun shine due to nuclear fusion of hydrogen into helium in their cores. But after a few billion years, the core hydrogen is fully converted to helium, and the star starts burning the hydrogen in a shell around the core.

Professor Bedding takes up the story: "When this happens, the outer part of the star expands and cools, creating a red giant. But at the same time, the helium core contracts and gets hotter. Eventually it's hot enough for helium to start fusing into carbon and oxygen. So there are two types of red giants: those that have started burning helium in their cores, and those that have not. From the outside, it's very difficult to tell the difference, but now asteroseismology has given us a way."

A key difference between the two types of red giant, in theory, should lie in the size and density of their cores. In the first phase, the dormant helium slowly shrinks and grows denser, but once it ignites, the pressure of escaping radiation should cause the core to expand again, and grow less dense. The changing core size and density should produce a measurable difference in the seismic oscillations affecting the two types of star.

"Indeed, it turns out that the red giants divide neatly into two groups based on observed properties known as mixed modes," continues Bedding, "and we can match these with the two groups of red giants. This result is a beautiful confirmation of the theories of stellar structure and evolution. Until now, almost everything we know about the lives of stars has come from theoretical calculations, but as in all science, it's vital to test theory by using observations."

However, while asteroseismology has helped confirm some long-standing ideas about red giants, that's not quite the end of the story. "More extensive analysis of Kepler data by several groups has turned up a puzzle," admits Professor Bedding. "The rotation rates in the cores of these red giants, which we can also deduce from asteroseismology, turn out to be only about ten times faster than the surface rotation. But theory predicts that the core of a red giant should rotate hundreds or even thousands of times faster than the surface. It's a puzzle that theoreticians are currently trying to solve, and is sure to shed new light on our understanding of stars."

What of future research? Hardware failures mean Kepler can no longer point accurately towards its original field of view, but Tim Bedding sees the bright side: "Kepler's new mission, K2, involves looking at a series of different fields for about 80 days each. This has an advantage for asteroseismology because it will allow us to sample oscillating stars in many different directions in the galaxy, rather than just one."

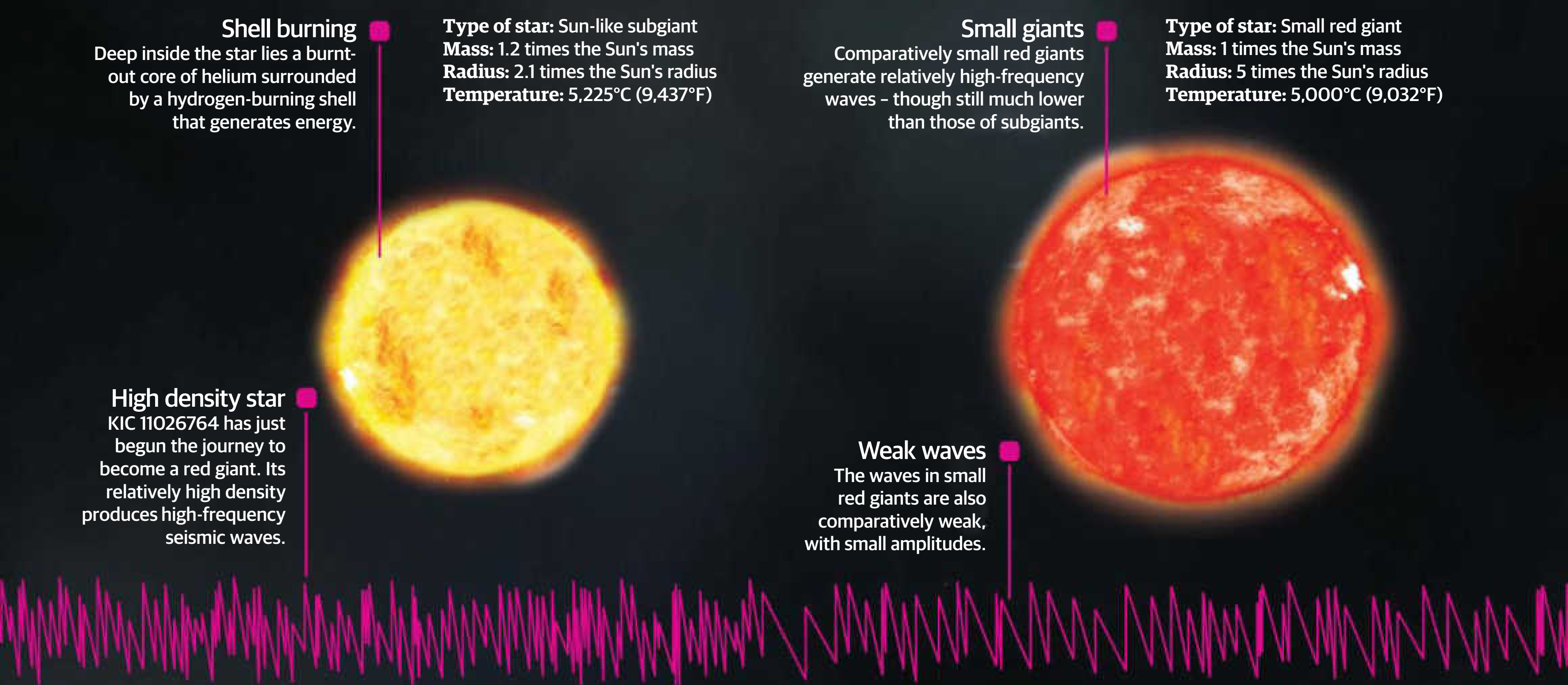
Beyond Kepler, the Sydney team and others will eagerly await planet-hunting missions such as NASA's TESS, due for launch in 2017, and the European Space Agency's PLATO, planned for 2024. And that's not all – a Danish-led network of ground-based telescopes called SONG is also being developed. With floods of information telling us more about a star's insides, we could soon know much more about them than ever before.

"By measuring the period of oscillations we can infer conditions deep inside the star, such as temperature" **Professor Tim Bedding**

Professor Tim Bedding is Head of the School of Physics at the University of Sydney, and leads a team of asteroseismology researchers

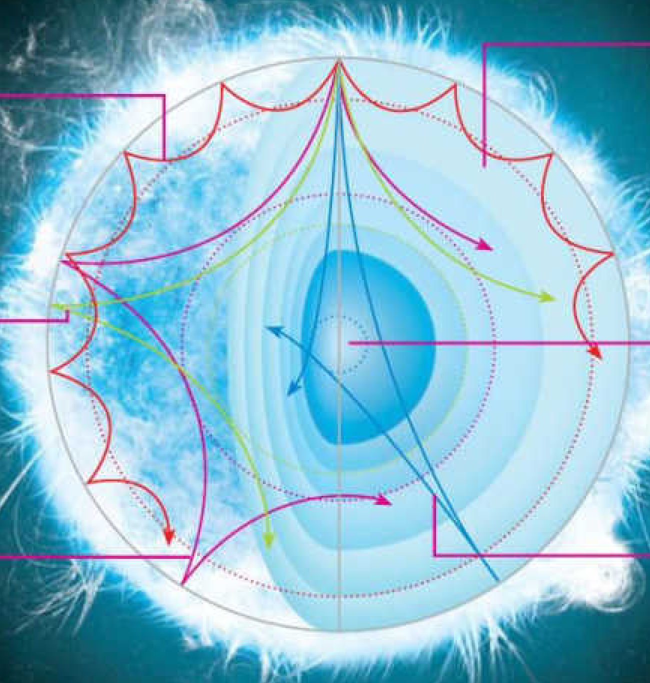
Stellar concert

Thanks to data from Kepler and other missions, it's becoming clear that all stars have their own oscillations, like instruments in an orchestra



The sound of stars

By influencing the three types of seismic waves passing through it, a star's internal structure affects the pattern of oscillations seen at its surface



f-mode waves
Surface-gravity or 'f-mode' waves are created at the surface and move across the star like waves on the ocean.

p-mode waves
Pressure or 'p-mode' waves are most similar to familiar sound waves, and are generated by local pressure changes inside the star.

g-mode waves
Gravity or 'g-mode' waves are generated where gravity counteracts the internal buoyancy of rising gas.

Layering
Just like light waves passing from air to water, the passage from one internal layer of a star to another with different properties can deflect waves, or even reflect them completely.

Core chemistry
The speed at which waves travel straight through the core reveals its composition and likely age – waves move faster through higher density materials like helium that accumulate over time.

Rotation
The rotation of a star's core influences waves passing through or near it, creating oscillation patterns that can reveal its rate of spin.

Bigger and cooler
As a red giant brightens and swells in size its surface cools because there is a far larger surface area for energy to escape through.

Type of star: Large red giant
Mass: 1 times the Sun's mass
Radius: 20 times the Sun's radius
Temperature: 4,000°C (7,232°F)

Slower and stronger
Seismic waves in bigger red giants are more powerful, but have lower frequencies as they move more slowly in the low-density stellar interior.

Strange giant
RR Lyrae stars are an unusual group of helium-burning, low-mass giants found mostly in ancient globular clusters.

Type of star: RR Lyrae star
Mass: 0.65 times the Sun's mass
Radius: 5 times the Sun's radius
Temperature: 6,000°C (10,832°F)

Cosmic lighthouse
These stars change in brightness every few hours, but Kepler data helps to explain long-term variations in their peaks and troughs.

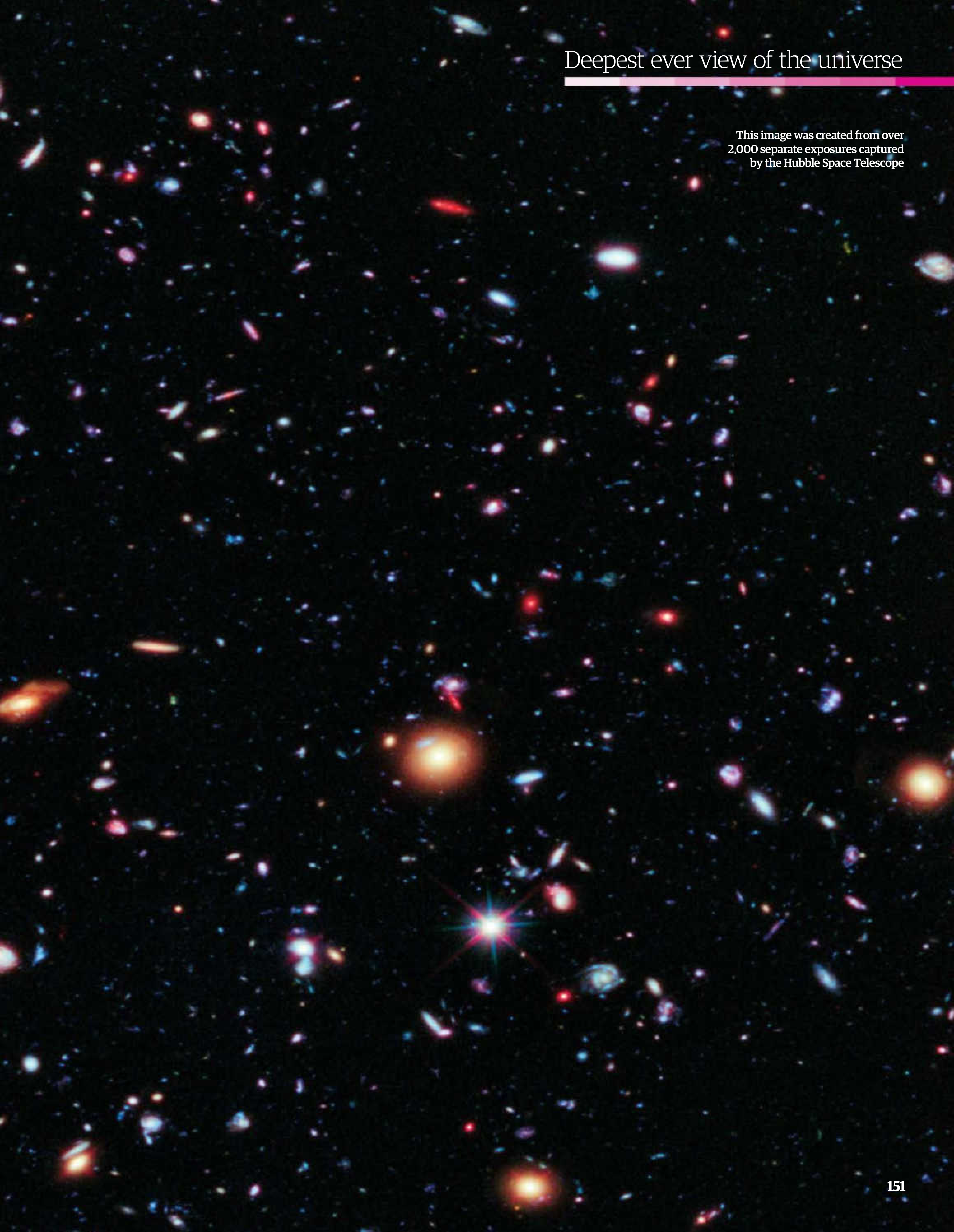
Deepest ever view of the universe

Hubble scientists have recorded the history of galaxies in this one image, from soon after the first galaxies were formed to their huge contemporaries

You are looking at one of the most extraordinary views of the universe ever created. It's called the eXtreme Deep Field or XDF and was assembled by combining ten years of NASA Hubble Space Telescope photographs taken of a patch of sky at the centre of the original Hubble Ultra Deep Field. This was an image of a small area of space in the constellation Fornax, created using Hubble Space Telescope data from 2003 and 2004. The new full-colour XDF image shown here uses the infra-red spectrum to reach much fainter galaxies, enabling new studies of the earliest galaxies in the universe. This has been achieved by incorporating well over 2,000 separate exposures from Hubble's two main cameras – the Advanced Camera for Surveys, which has been operational since 2002, and the Wide Field Camera 3, which was installed during the very last service of the telescope performed in 2009.

The image represents a valuable astronomical tool which will be used by scientists for many years, showing more than 5,000 galaxies, among which is a candidate for the most distant galaxy yet discovered. Should this be confirmed, the galaxy known as UDFj-39546284 is being seen just 460 million years after the Big Bang. In fact, most of the galaxies visible in the XDF are seen when they are in their infancy, often colliding and merging together and these images can be followed up by the other, more powerful telescopes of the future such as the James Webb Space Telescope, which should be operational by 2018 and offer even deeper views into the history of the universe.

Deepest ever view of the universe



This image was created from over 2,000 separate exposures captured by the Hubble Space Telescope

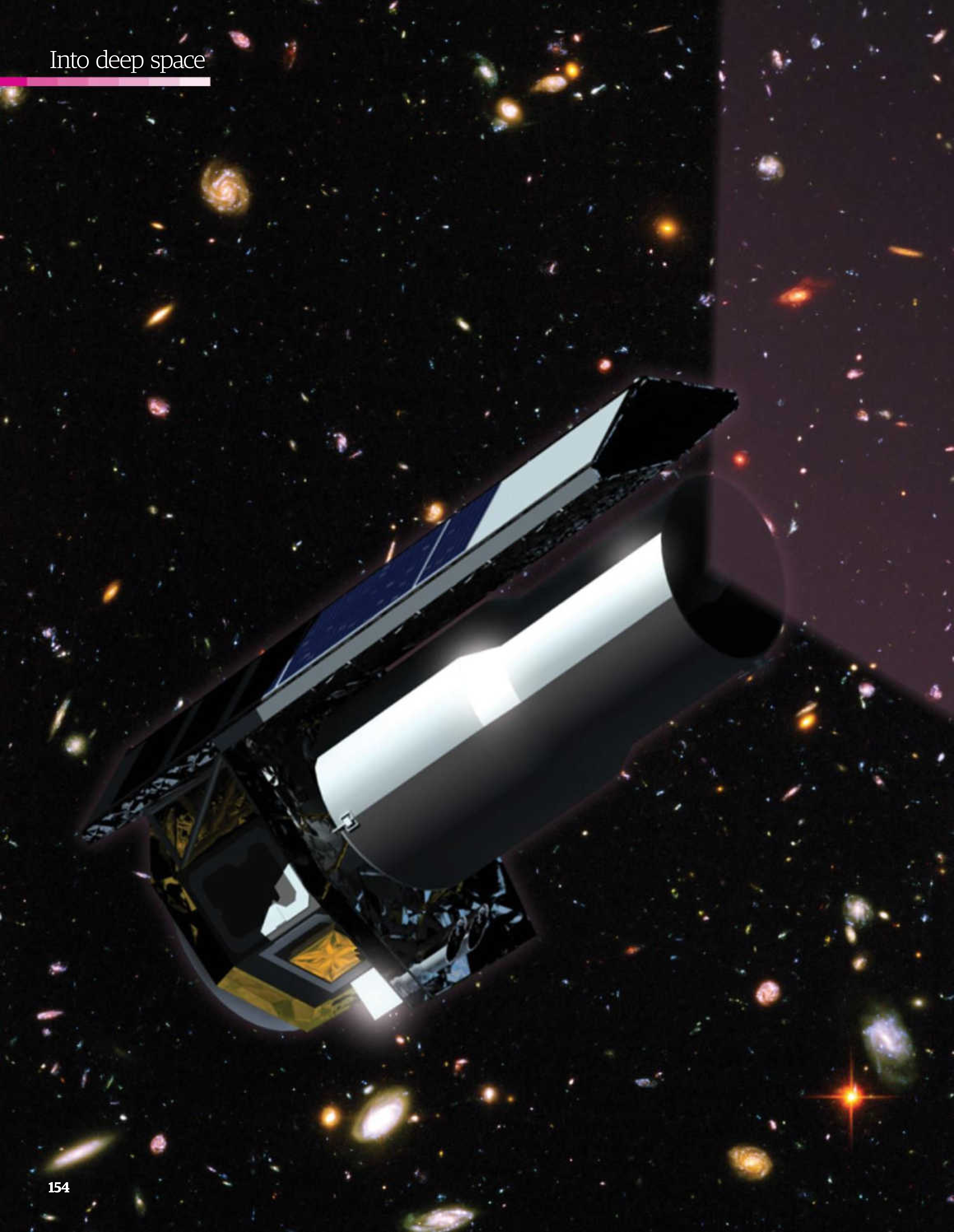
Bubble Nebula

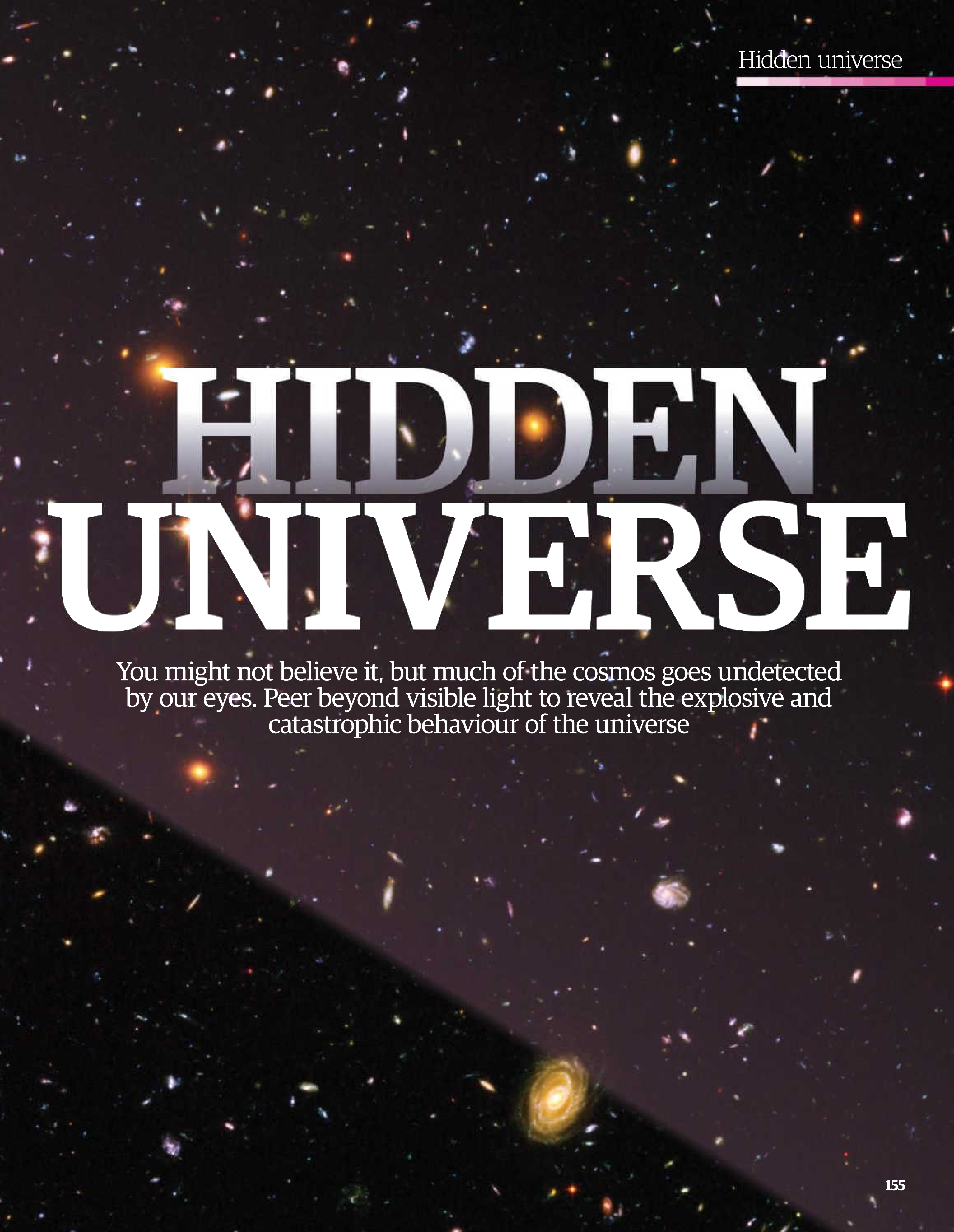
What's behind this interstellar phenomenon floating in the far reaches of space?

11,000 light years away in the Cassiopeia constellation can be found this fascinating nebula that at first glance bears resemblance to a bubble. Also known as NGC 7635, the ten-light-year-wide Bubble Nebula is an emission nebula that was formed from a young and hot star at its centre.

It was first discovered in 1787 by William Herschel, and since then it has been the subject of detailed observations. Near the centre of the bubble can be seen the bright star BD+60°2522, several hundred thousand times more luminous and nearly 50 times more massive than the Sun. This star blasted out intense radiation and a fierce stellar wind, which in turn interacted with denser material in a surrounding molecular cloud and formed the Bubble Nebula.

The nebula itself is one of three shells of gas originating from BD+60°2522. This star also ionises the shell by continuously emitting energetic radiation, which causes it to shine. Aside from the interesting shells that glow from the interaction with its central star, some wisps near the bottom right of the image are the remnants of a supernova explosion thousands of years old.





HIDDEN UNIVERSE

You might not believe it, but much of the cosmos goes undetected by our eyes. Peer beyond visible light to reveal the explosive and catastrophic behaviour of the universe

Radio, depicted in blue, reveals an incredible amount of hydrogen in our nearest Ultraluminous Infrared Galaxy (ULIRG), Arp 220. The galaxy is the result of two galaxies merging into one. The image below shows Arp 220 as imaged by the Hubble Space Telescope

INTERVIEW

Charles Blue

National Radio Astronomy Observatory (NRAO)

"Radio astronomy is utterly essential for understanding the universe, since optical telescopes only see bright stars and objects illuminated by them. Radio telescopes, on the other hand, see the cold, dark and distant universe. This includes nurseries that form stars, clouds of hydrogen gas, molecules in galaxies, energetic particles accelerated by super dense black holes and galaxies near cosmic dawn. These objects and in fact all objects in space, shine at radio wavelengths. When combined with other telescopes operating at different wavelengths, radio astronomy unlocks even more amazing information, supplying us with a more complete picture of the cosmos."

If we just relied on our eyes, we'd find that we would be blind to most of what the universe has to offer. There would be so much that we would completely miss, from the explosive nature of gamma-ray bursts, to the dusty skeletons of galaxies and even the radiation left behind by the Big Bang. This is because the universe emits light that goes well and truly beyond what our eyes alone can see. Visible light, which is the light that we see making up our everyday surroundings, is just one small part of the electromagnetic spectrum. This runs all the way from low-energy radio waves through to astonishingly high-energy gamma rays. To us, anything that's regarded as outside of the visible part of the spectrum, we just can't see. You might be surprised to learn that we produce this hidden light on Earth too. Think of infrared night vision goggles, the X-rays you might get to see a broken arm with, ultraviolet security tags or radio waves transmitting music and telephone calls across the planet. In space, these other wavelengths of light are everywhere, coming from all kinds of cosmic objects. It's like a hidden universe, but luckily for us, astronomers are able to tune in to these other wavelengths to make the invisible visible.

Light is a funny thing, it is able to act like both a wave and a particle at the same time. This is why we say that a photon of light can have a wavelength. The longest wavelengths are radio waves, which range from a millimetre in length to many kilometres. Meanwhile, the shortest wavelengths on the electromagnetic spectrum belong to gamma rays and can be as small as just a trillionth of a metre. So to see this hidden light, astronomers need a variety of tools, from giant bowl-shaped radio dishes that can be seen from miles around, to detectors in orbit above Earth's obscuring atmosphere.

This other light remained hidden until its discovery at the beginning of the 19th century. It was the year 1800 when William Herschel used a prism to split light into a spectrum of colours and measured the temperature of each shade. He came to the conclusion that there must be an extra unseen colour beyond red because his thermometer was responding to light in the spectrum that he could not see – the infrared. A year later, the German scientist Johann

Radio

The start of radio astronomy

In the 1930s, astronomer Karl Jansky found there were radio waves coming from the Milky Way galaxy. However, even before then astronomers such as James Clerk Maxwell speculated that radio waves could be observed from astronomical sources.

Revealing the radio universe

With a gathering of radio telescopes, we are able to make part of the invisible universe visible

1 A very large collection
The Atacama Large Millimetre Array (ALMA) is made up of 66 dishes, all up to 12m (39ft) across and weighing in at 100 tons each. Each one of the dishes that comprise ALMA gathers faint radio waves from space.

2 Going digital
ALMA's dishes are able to turn the incoming signals from analogue into digital by converting the radio waves into binary computer code.

3 Supercomputer power
The digital data is sent along 15km (9.3mi) of optical fibres to a supercomputer whose power matches that of 3 million laptops.

4 Dished out
When astronomers around the world get the data, they are able to turn it into images that are ten-times sharper than those that are taken by NASA's Hubble Space Telescope.

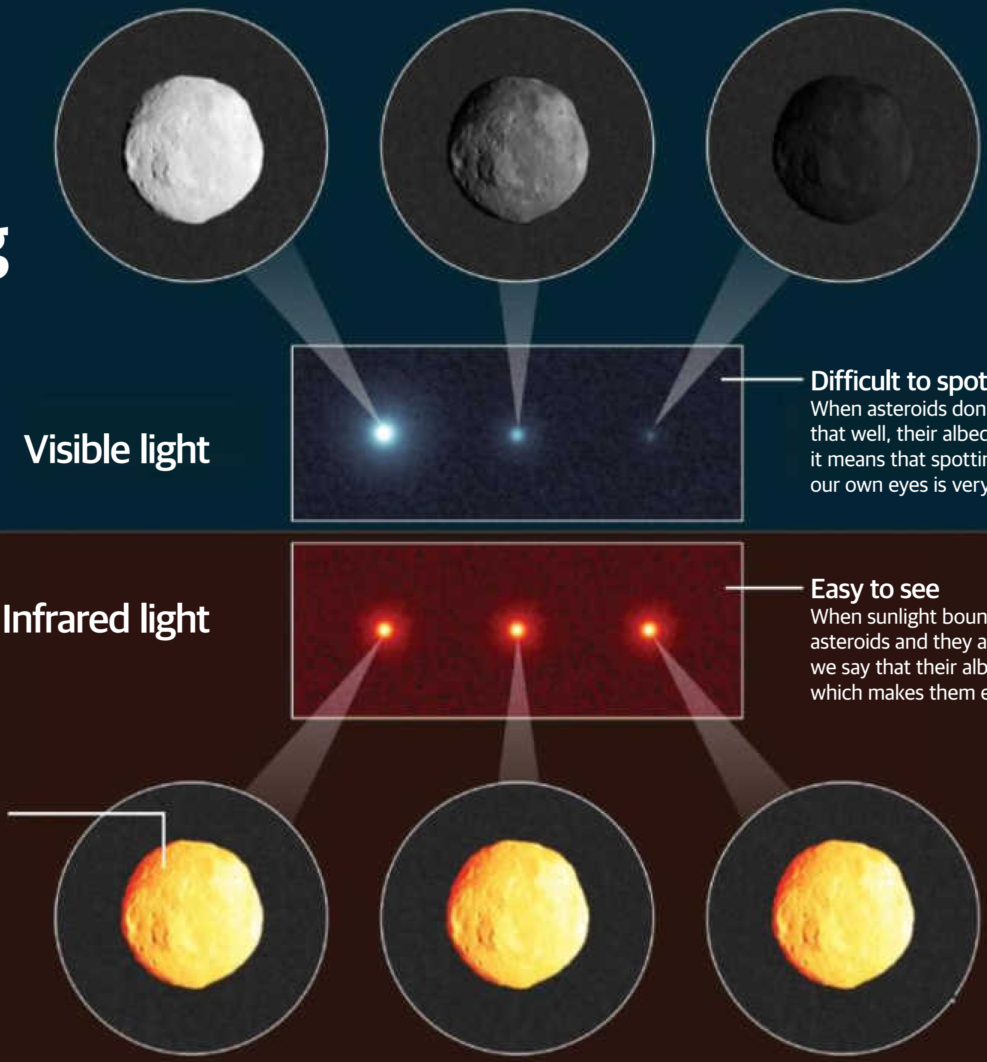
A large array
Spread out across an area of 6,500m^2 (70,000ft^2), these large radio antennas have a combined surface area about the size of a football pitch.

Changing the goal posts
It's possible for the dishes to be moved closer together or further away, depending on what astronomers are scouting the universe for. Vehicles capable of transporting a radio telescope weigh around 130 tons and have 28 wheels.

Microwave

A major microwave discovery
A massive turning point in astronomy came in 1965, when Arno Penzias and Robert Wilson discovered the Cosmic Microwave Background – the thermal radiation left over from the Big Bang that brought the universe into existence.

Revealing hidden asteroids



Difficult to spot
When asteroids don't reflect light that well, their albedo is low and it means that spotting them with our own eyes is very difficult.

Easy to see
When sunlight bounces off asteroids and they are very bright, we say that their albedo is high, which makes them easy to see.

Asteroid location made easy
Whatever the albedo of an asteroid, infrared light is able to uncover it with ease, making finding these lumps of space rock simple.

Ritter conducted a similar experiment, but this time found that unseen light beyond violet had the ability to darken paper soaked with silver chloride. Ultraviolet light had been discovered.

Our planet's atmosphere doesn't want us to see some of this hidden light from the universe and it does a pretty job of absorbing infrared light using its water molecules, while its ozone layer blocks harmful ultraviolet. In fact, other than radio, microwave and infrared astronomy, most of this hidden light needs a very strong space telescope high above the atmosphere to see it. That's partly why our understanding of the universe has grown so much since the Space Age, because we can now launch telescopes far into Earth's orbit to study the mysterious hidden universe.

So lets imagine that we're able to put on infrared goggles and X-ray glasses – what can we see? Our own galaxy, the Milky Way, is a completely different beast when we look at it in other wavelengths. Galaxies, including our own, are made up of lots of hydrogen gas. Atomic hydrogen radiates at a wavelength of 21 centimetres (8.3 inches) and radio astronomers are able to map where this atom is in our galaxy to give them an indication of the size and shape of the Milky Way, along with how fast it's actually spinning.

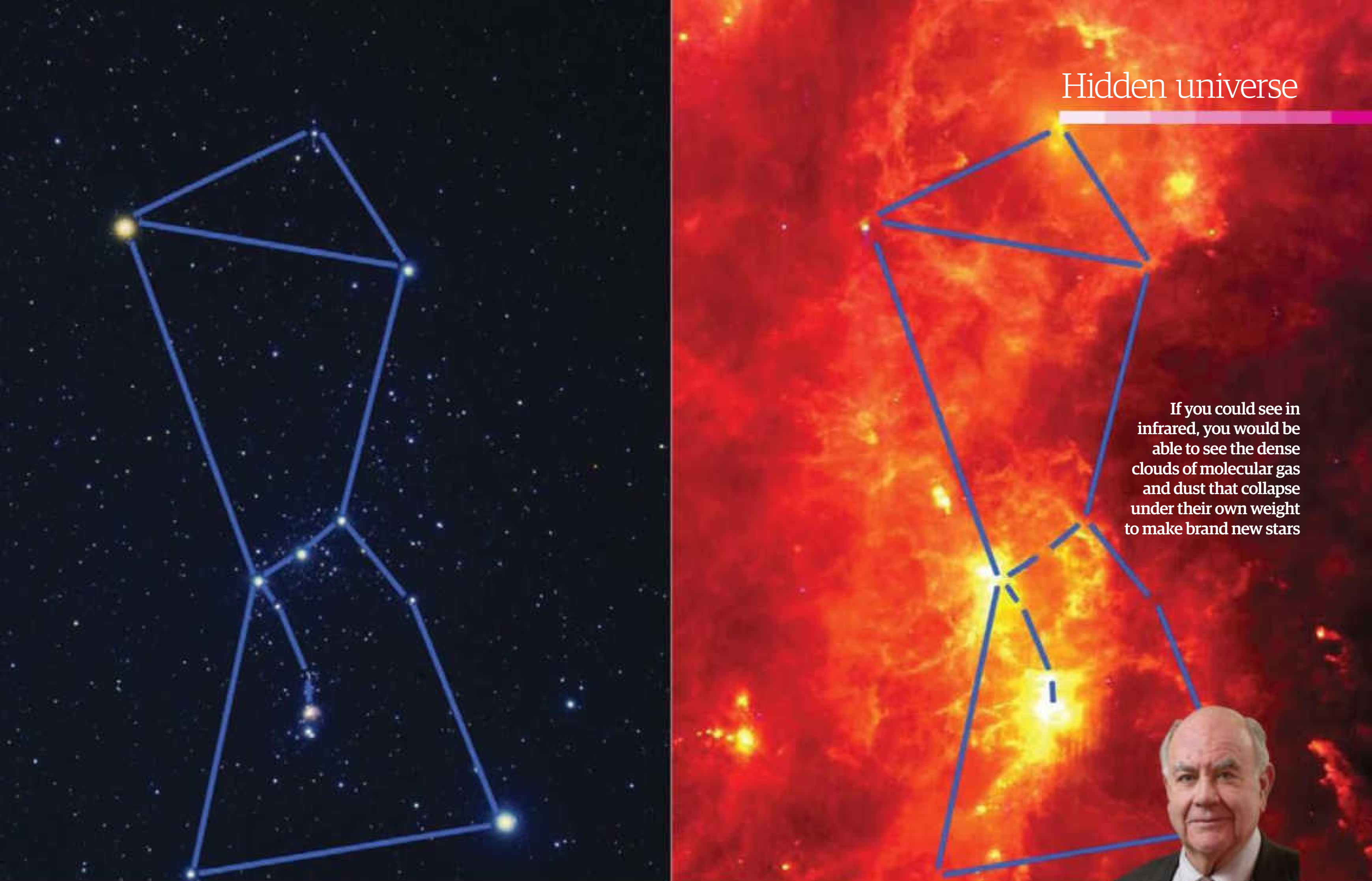
But there are many more things in the galaxy that spit out radio waves. There are pulsars, which are spinning dead stars discovered by astronomer Jocelyn Bell in 1967. She found a regular 'beep-beep-beep' pulse coming from these objects in the form of radio waves. These dead stars, which come from stellar explosions commonly known as supernovas, emit beams of radio waves and as they spin they flash these beams at us over and over again, creating the dramatic appearance of a pulsing object.

When supernovas explode, they leave behind a nebula of gas and dust blasted out by the explosion. The brightest radio objects in the sky are supernova remnants, such as the Crab Nebula, also known as M1 in the constellation Taurus. M1 is the remains of a massive star that blew itself to smithereens in the year 1054. Supernova remnants like M1 also produce radio waves, when a powerful stream of ultraviolet radiation coming from the pulsar at its heart excites the gas in the nebula and causes it to radiate in radio waves. There's more to M1 than radio though. Let's turn the dial on the electromagnetic spectrum and look at it in infrared light, which tends to come from cooler, lower energy objects. In this remnant, it is the

> "Our understanding of the universe has grown so much since the Space Age, because we can now launch telescopes into orbit to study the hidden universe"

Infrared

Watching star birth in infrared
Thanks to the launch of infrared space telescopes such as the Spitzer Space Telescope and the Herschel Space Observatory, we've been able to look at the birth of young stars and capture infrared light being thrown out by exoplanets known as hot Jupiters.



If you could see in infrared, you would be able to see the dense clouds of molecular gas and dust that collapse under their own weight to make brand new stars

cool dust that was created in the mighty supernova explosion that we can see in infrared light. Now turn the dial again into visible light and what we see is hot gas glowing at tens of thousands of degrees. Move again past visible light and into the ultraviolet and X-ray spectrums and we see that the nebula glows at each of these wavelengths. This tells us that there is a powerful magnetic field around the pulsar in the middle. Subatomic particles, known as electrons, have an electric charge that causes them to spiral around wildly in the magnetic field. As they do so, they give off photons of energy in a process scientists call synchrotron radiation. These photons are what we see in the Crab Nebula at ultraviolet and X-ray light and wherever astronomers see synchrotron emission in the universe, they know that there must be a magnetic field lurking around somewhere.

Massive stars that explode as supernovae are found to glow brightly and possess swelteringly hot temperatures of up to 20,000 degrees Celsius (36,000 degrees Fahrenheit). Things this hot radiate in visible light but also in ultraviolet light and space telescopes such as NASA's Galaxy Evolution Explorer (GALEX) seek out sites of massive star formation, not just in our galaxy but in other galaxies, by looking for their ultraviolet light. On the other hand, cooler stars glow best in infrared light, meaning that telescopes such as NASA's Wide-field Infrared Survey Explorer (WISE), along with their Spitzer Space Telescope, are able to sniff them out. These cool stars include the pint-sized red and brown dwarfs that can be as cool as a planet like Jupiter, or even cooler. WISE has found several brown dwarfs just a few light years away that are very dark in visible light, but are a bit brighter in infrared – at a bearable room temperature, they are found to glow quite faintly.

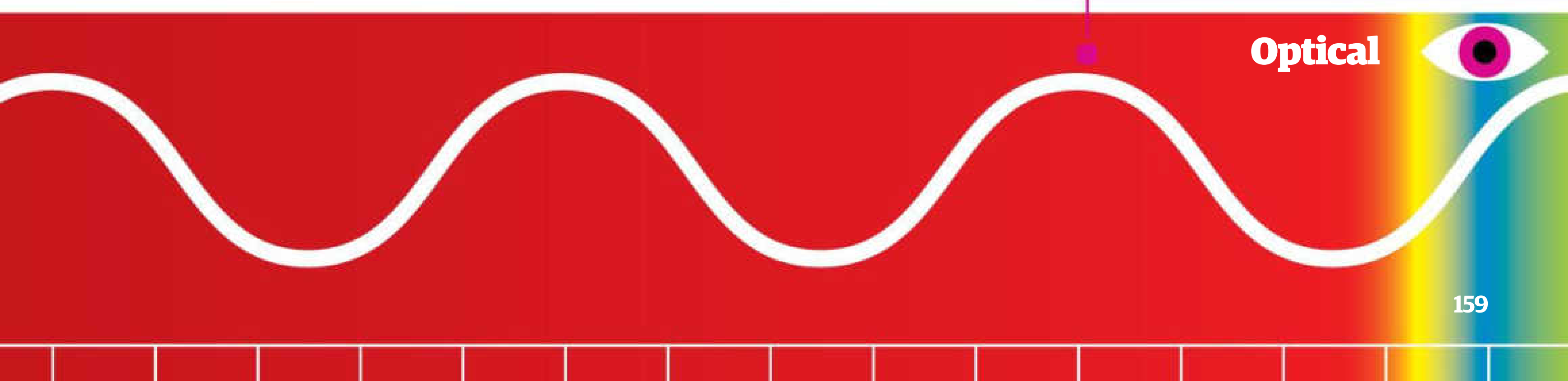
In case you were wondering, the Sun puts out most of its light in the visible range, but also produces infrared, X-rays, radio waves and ultraviolet too. Solar space telescopes like the Solar and Heliospheric Observatory (SOHO) and the Solar Dynamics Observatory are able to look at the Sun with cameras designed to observe in an array of wavelengths. Hot active regions on the Sun can produce lots of ultraviolet light, while the most powerful solar flares can throw out bursts of energetic X-rays. The Sun also

INTERVIEW

Giovanni Fazio

Principal investigator of the Spitzer Space Telescope

"Infrared observations have helped us to detect cold objects such as brown dwarfs and exoplanets, which are invisible at visible wavelengths. They are required to study galaxies in the very early universe. Infrared radiation can penetrate the dense dust in the interstellar medium whereas visible light cannot. This is important if we want to observe and understand the earliest stages of star formation in dense clouds of dust and gas. Interstellar dust absorbs visible and ultraviolet light and re-radiates it at infrared wavelengths. Infrared radiation can therefore be very helpful when used to map the distribution of dust in a galaxy. Infrared wavelengths are an extremely important element when it comes to searching for new life in the expanding universe."



Making a supernova remnant visible

It takes snaps in a few types of light to reveal a cosmic object in its true glory and supernova remnant, Cassiopeia A, is no exception

Hidden in visible

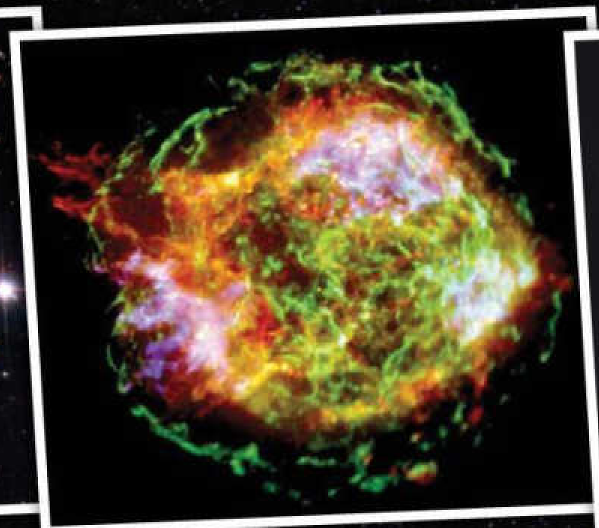
Where has Cassiopeia A gone? In this visible light image from the Hubble Space Telescope, the supernova remnant is barely visible. Here green represents glowing oxygen, red and purple are from sulphur gas and blue is light from hydrogen and nitrogen gas. The total exposure time was 2.3 days.

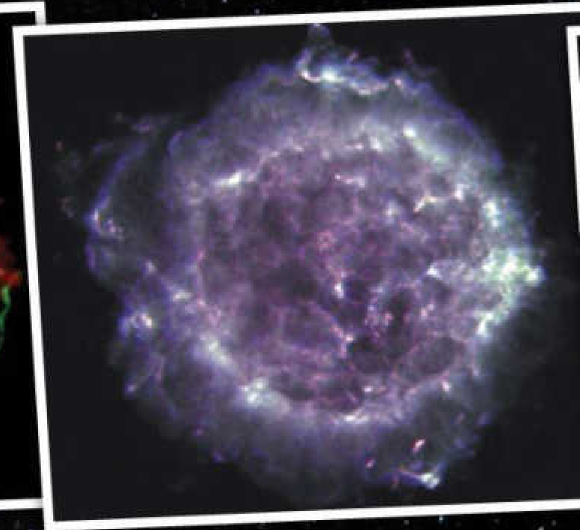
Getting to the heart in X-ray

This image was taken by the Chandra X-ray Observatory, which collected X-ray light for over 11.5 days. Presented in false colour, the outer ring, coloured green, is the current location of the shock wave from the supernova. Red indicates the lowest energy X-rays and blue shows the highest energy.

Revealing in radio

This radio image of Cassiopeia A was made by the Very Large Array, which is made up of 27 radio telescopes based in New Mexico. The image was made at three different frequencies: 1.4GHz, 5GHz and 8.4GHz, corresponding to wavelengths of 21.4cm (8.4in), 6cm (2.4in) and 3.5cm (1.4in).





"Gamma-ray bursts have been seen to explode from almost 13 billion light years away"

radiates at longer wavelengths, constantly blaring out in radio waves. In fact, our own star was one of the first objects to be studied with radio waves.

So far we've been kicking back with the not-so-energetic radio, but what occurs with the high-energy photons that belong to gamma rays? These come from only the most extreme objects and the first gamma-ray astronomy was done not by a dedicated space telescope, but by military satellites designed to search for gamma rays from tests of nuclear bombs during the Cold War. The satellites did detect gamma rays, but they weren't coming from nuclear bombs. Instead they were travelling from the depths of space and for a quarter of a century nobody had a clue what was causing these bursts, or even whether they were from a local source or far away. Officials realised that if they were coming from far away, then their strength must make them the most powerful outbursts since the Big Bang.

In 1997 the mystery was solved in something of a role reversal, when scientists used the visible universe to reveal details about the hidden universe. The European BeppoSAX satellite detected the gamma rays from one of these mysterious bursts and an alert was swiftly sent out to astronomers all over the world. The William Herschel Telescope in the Canary Islands was able to point toward the scene of the burst and saw a faint afterglow of visible light from a supernova in a distant galaxy, one that lays an astonishing 6 billion light years away. This was no ordinary supernova, but the destruction of one of the most massive stars in existence as it produced a black hole. The gamma rays are created by twin beams of high-energy particles that shoot out from the exploding star in magnetic jets, causing the electrons to spiral around the magnetic fields so strongly that they produce immensely powerful gamma rays. Since then, gamma-ray bursts have been seen to explode from almost 13 billion light years away. These bursts are the most powerful explosions in the universe and we only found them by accident!

Gamma rays don't just come from exploding stars. The Milky Way also sends out these high-energy rays. NASA's Fermi Space Telescope was designed to observe the universe in gamma rays, but what it found in the heart of our galaxy was truly amazing and surprised everyone.

Galaxies shine in light all across the electromagnetic spectrum and the dust in spiral arms is sensitive to infrared, massive star formations glow in ultraviolet and hydrogen gas emits radio waves. Although the supermassive black holes that reside at the heart of most galaxies don't emit any radiation that we can detect, their interactions with the matter surrounding them radiate at practically every

UV

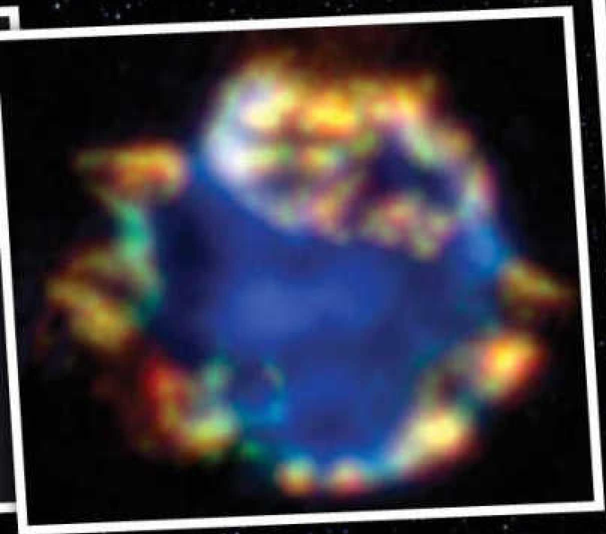
Hot in the ultraviolet

This light is thrown out by very hot objects such as stars in the early or late stages of their evolution. As we're able to capture these stars at such points in their lives, we can understand their development.

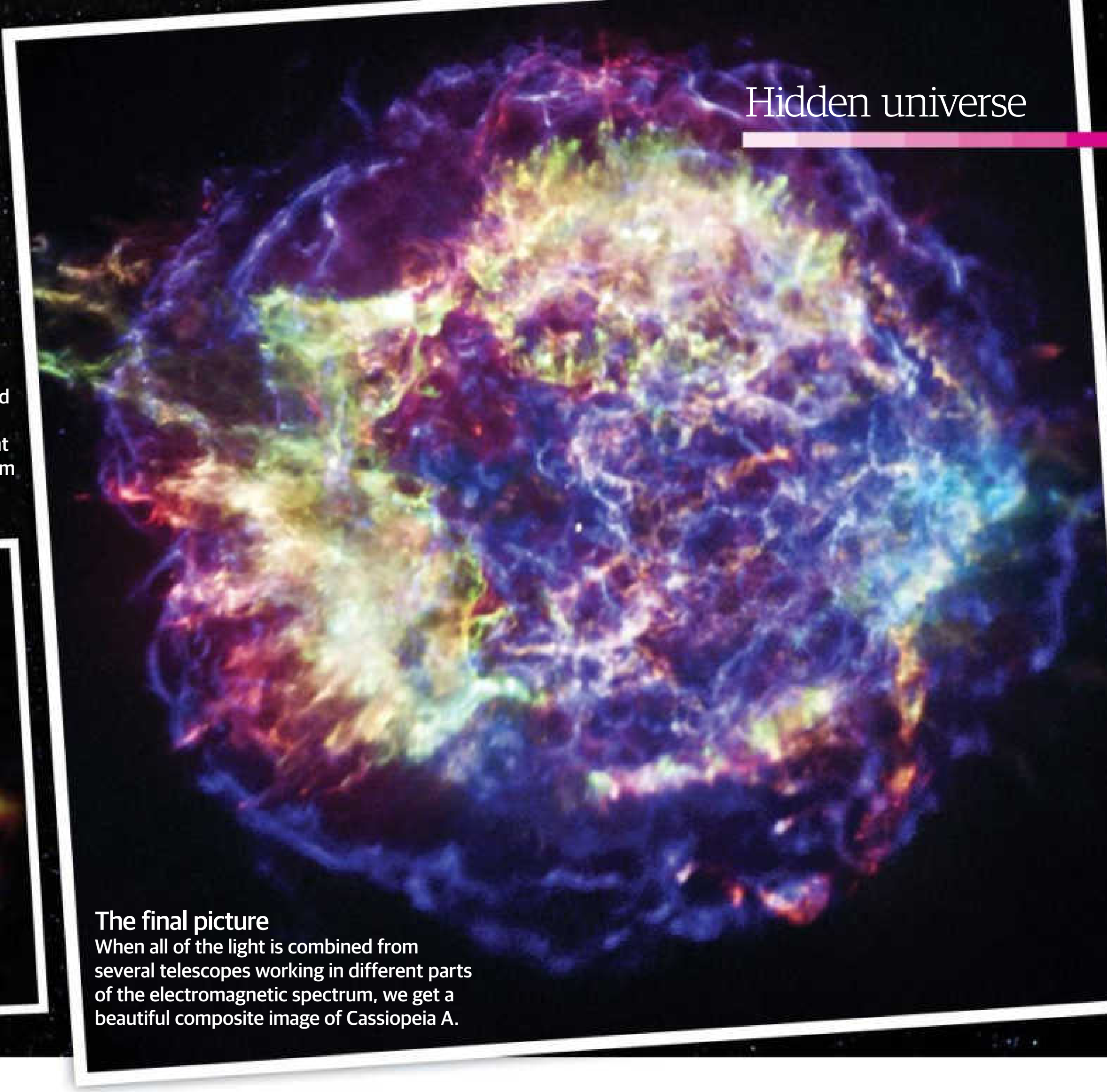
X-ray

Black holes burping X-rays

Astronomers discovered that when a black hole chows down on gas and dust, it'll burp out high emissions of X-rays after its meal.



Collecting the infrared
This picture is the Spitzer Space Telescope's infrared view of Cassiopeia A. It too is in false colour, with different colours indicating the emission at different infrared wavelengths. Blue represents emission from silicon gas, green is argon and red is emission from dust. Yellow is where the red and green overlap.



The final picture
When all of the light is combined from several telescopes working in different parts of the electromagnetic spectrum, we get a beautiful composite image of Cassiopeia A.

wavelength possible. An active black hole, such as the monster inside the giant elliptical galaxy, Messier 87, is a powerful emitter of radio waves. It beams a jet of particles moving at nearly the speed of light that can be seen in visible light but also at other wavelengths, such as X-rays. Much quieter is the Milky Way's black hole, which is not gobbling up much gas at all. Occasionally we will see it flash in X-rays when it swallows something small like an asteroid, which is why astronomers were astonished when Fermi discovered two giant jets of particles, each pointing in opposite directions at the centre of the galaxy. These were spilling out to form bubble shapes shining in gamma rays. Each Fermi Bubble is about 25,000 light years tall and came from a dramatically violent event that happened in the centre of the galaxy several million years ago. This would have happened when the black hole consumed a large amount of gas, causing it to fiercely erupt, or during an intense period of star formation with stars so hot and massive that their stellar winds were able to blow out and heat large amounts of gas from the centre of the galaxy. These bubbles are immensely active, but are completely invisible to our eyes in the always surprising hidden universe.

But maybe the biggest thing to be seen in the hidden universe is the Big Bang itself. We cannot see the moment of formation that took place 13.8 billion years ago, but the heat energy from the Big Bang still fills the universe to this day, albeit a lot cooler than in the beginning. Today it is only -270 degrees Celsius (-454 degrees Fahrenheit) and this remnant heat energy shines brightest in microwave light. Telescopes have made maps of this Cosmic Microwave Background (CMB) radiation and from it scientists can figure out things such as how galaxies grew. Funnily enough, we wouldn't need a telescope to detect the CMB radiation because on analogue television sets, a small portion of the static comes from these microwaves.

"Fermi discovered two giant jets of particles, each pointing in opposite directions at the centre of the galaxy"

The cold universe tends to radiate at the longer wavelengths of the electromagnetic spectrum, such as radio, microwaves and infrared. Infrared is sometimes called thermal emission, because things that are warm around us, such as our bodies or a fire, shine brightly in infrared light. Meanwhile, the most energetic action in the universe produces lots of ultraviolet, X-rays and gamma rays. It may seem like astronomers have revealed all of the universe, but there is still plenty that remains unseen. Within the hidden universe, nothing is beyond possibility.

Gamma Ray

Highly energetic astronomy
There's nothing more energetic or harmful than a gamma ray. They can be found in solar flares, as well as in the catastrophic stellar explosions known as supernovae and the even more devastating hypernovae.

When galaxies collide

These two interacting galaxies are providing us with a rare opportunity to observe a galactic collision

This stunning image, taken by the Hubble Space Telescope, shows the individual galaxies UGC 1810 (top) and UGC 1813 (bottom) in the process of colliding. Together, this pair of interacting galaxies is known as Arp 273. The interaction of galaxies is thought to be relatively common in the universe, particularly within galactic clusters, however, the opportunity to directly observe one such as this is incredibly rare.

The two galaxies are located around 300 million light years from Earth in the Andromeda constellation. A collision is actually thought to have already occurred, with UGC 1813 passing through the five times more massive UGC 1810. As a result, the smaller galaxy is now showing signs of intense star formation at its nucleus. It is possible, though, that they will collide again in the future due to their gravitational attraction.

Most galactic collisions result in the merging of the two galaxies' cores, but it's unknown if that will happen in this example. What can be seen is a 'bridge' of sorts between the two where their spirals have been pulled apart by the other. It is thought that the interaction of Arp 273 may bear similarities to the eventual fate of our own galaxy when we collide with Andromeda in around four and a half billion years.

The Sombrero Galaxy

The space phenomenon that's two types of galaxy at once

Located approximately 28 million light years from Earth, this odd-shaped galaxy has been the focus of much attention from scientists around the world. The Sombrero Galaxy, or Messier 104, gets its name from its somewhat hat-like appearance. The bright galaxy is found towards the southern edge of the Virgo cluster of galaxies.

The Sombrero Galaxy contains about 2,000 globular clusters, collections of up to a million old stars held together by gravity that are often found in the halo of galaxies. By comparison, our Milky Way only has about 200. The Sombrero also contains several hundred billion stars and is approximately 50,000 light years across, around half the diameter of the Milky Way.

Around the brim of the galaxy are thick dust lanes that block the light at the centre, while the central bulge is made of old stars. Although the disc might be thin, the bulge, containing a black hole billions of times more massive than the Sun, can be seen extending both above and below the galaxy in this image from NASA's Hubble Space Telescope.

One of the most interesting things about the Sombrero Galaxy is that it seems to have a split personality. Most galaxies we know of are either spherical clusters of stars or slender discs, but the Sombrero appears to be both. Observations by NASA's Spitzer Space Telescope suggest that it is a round elliptical galaxy with a flat disc inside. The cause of this unique structure is unknown, although it's possible the Sombrero Galaxy was inundated with gas over 9 billion years ago, forming this additional mini-galaxy within.

Galactic ghosts

Eight shadowy galaxies that were briefly lit up by a powerful blast of energy

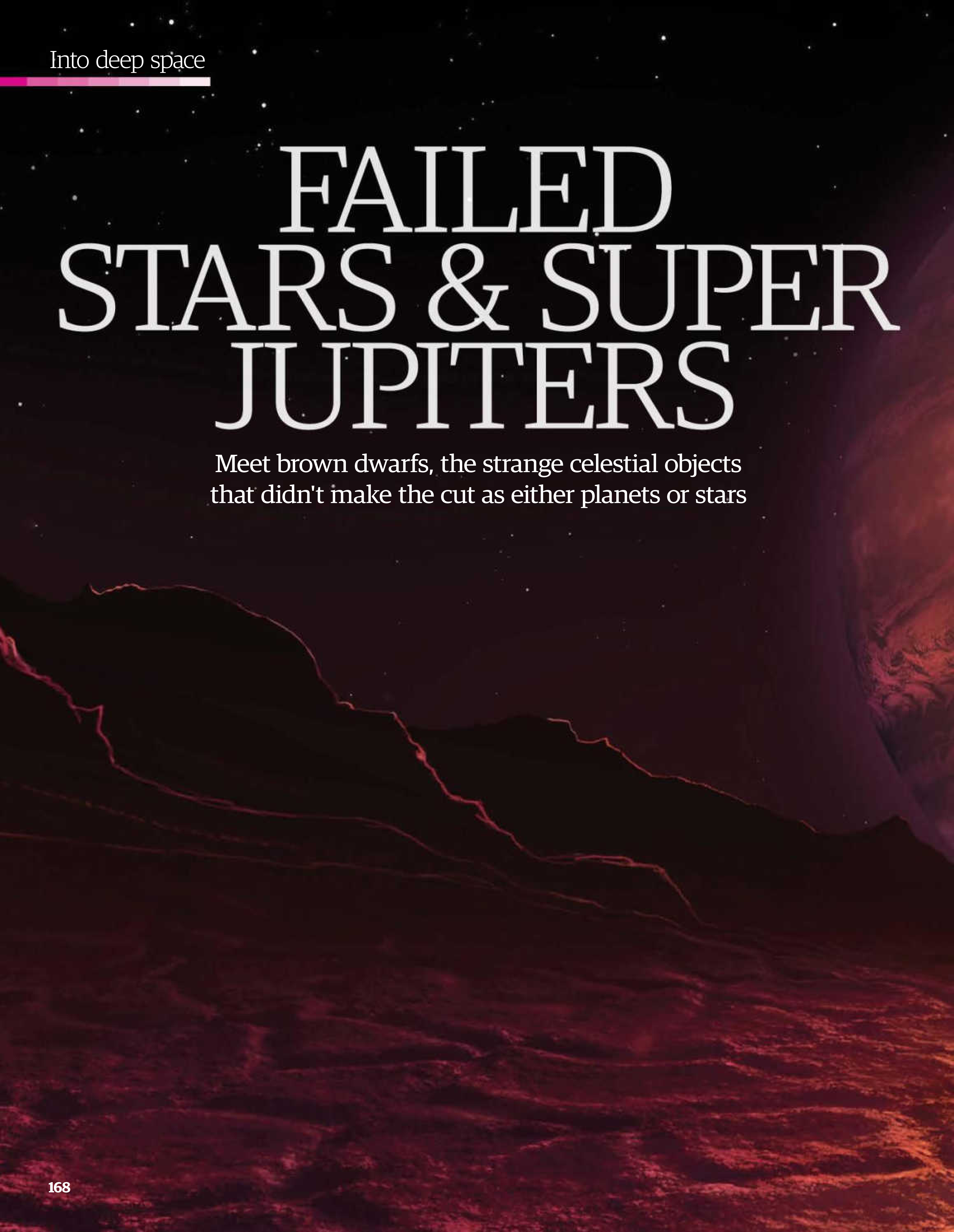
Each of these wispy celestial objects is a galaxy photographed by the Hubble Space Telescope. Most of the filaments that surround them, which show up mainly in green, were practically invisible until the energetic quasar that surrounds the supermassive black hole in their host galaxy lit them up with an extremely powerful blast of radiation. This caused elements in the filaments, including oxygen, helium and sulphur, to absorb the energy and release it gradually as light. Each element glows in a different colour and green, the most abundant colour in these images, is ionised oxygen. The process is called photoionisation and the filaments will glow for many thousands of years after having been ionised – although this period is just a blink of an eye on a cosmological scale.

The far left image on the top row shows the Teacup galaxy. A supermassive black hole at its core is actually blasting away the raw materials needed for continued star formation.

The once-invisible filaments of these galaxies have been illuminated by the radiation that surrounds their supermassive black holes

FAILED STARS & SUPER JUPITERS

Meet brown dwarfs, the strange celestial objects that didn't make the cut as either planets or stars



The brown dwarf is seen as a stellar failure, a dropout from the school of star formation. These gigantic objects with their puffy gaseous outer layers, are the universe's students that didn't quite make the grade. You see, in brown dwarfs, nuclear fusion – the process that gives stars their power – has given up the ghost, leaving them relatively cold and some no hotter than the human body. Neither planet nor star, brown dwarfs fall into the grey area between the most massive gas giant planets like Jupiter (which is why they're known as 'super Jupiters' because of their massive, gaseous nature) and the smallest stars. Their existence blurs the lines between what is a planet and what is a star and forces us to question the differences between how planets and stars form.

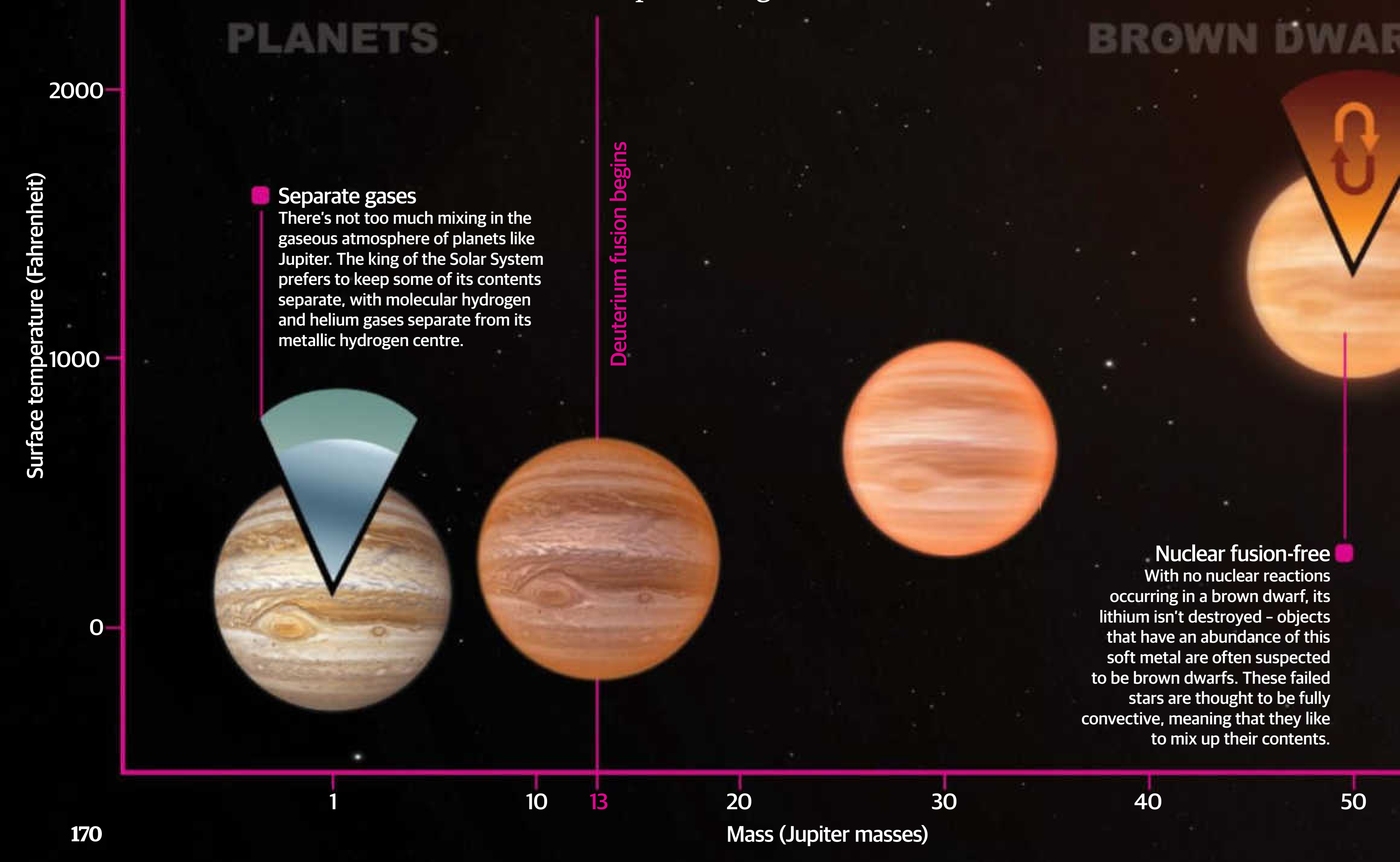
Stars form when clouds of molecular gas collapse under gravity and condense until the pressure and temperature at the centre of the collapsing cloud is so great, that nuclear fusion reactions – which turn nuclei of the element hydrogen into the heavier helium nuclei – ignite. This kind of top-down formation is one of the key differences between how stars and planets form. Meanwhile, the worlds of our Solar System and many others that astronomers have been studying over the past 20 years form through a bottom-up process, where a core gradually builds up, becoming bigger and bigger. For the most massive planets, the core has enough gravity to begin stealing gas from the proto-stellar nebula around it, and this is where gas giants such as Jupiter and Saturn got their hefty atmospheres.

Brown dwarfs form like stars, collapsing directly out of a gas cloud like a star in a top-down process. Clearly they are intended to become stars, but

"Smelling a brown dwarf's atmosphere wouldn't kill you, but it would stink pretty bad, like rotten eggs with a hint of ammonia" **Dr Amy Mainzer, NASA Jet Propulsion Laboratory**

Separating the planets from the stars

More massive and hotter than most planets, lighter and cooler than stars



something happens along the way that causes them to become runts of the stellar litter, smaller and cooler than even the chilled-out red dwarf stars.

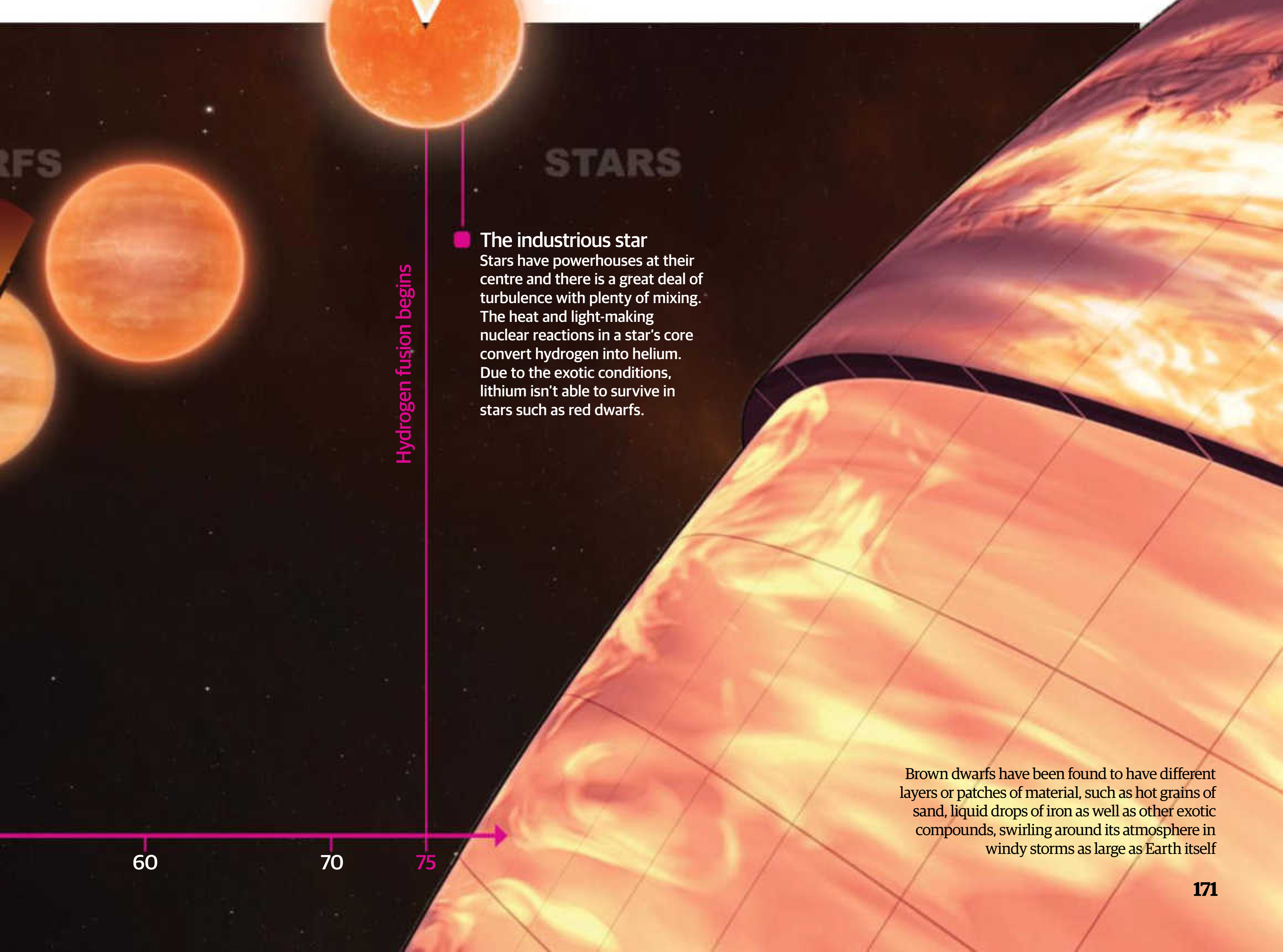
Actually, the universe seems to favour smaller objects. The so-called mass function describes the distribution of masses of the objects that are created in a star-forming nebula. A handful will be massive stars that will one day die as supernovae. More will be Sun-like stars. Even more will be red dwarfs, smaller and cooler than our Sun. And the most common type of object that will form in a nebula will be brown dwarfs. This is backed up by observations with the Hubble Space Telescope of the Orion Nebula, which discovered 50 brown dwarfs amid the newborn stars of the Trapezium Cluster. There will undoubtedly be more brown dwarfs in the Orion Nebula, but they are difficult to spot because they are so cool and dim. Hubble used its near-infrared camera to find the brown dwarfs because at their low temperature, brown dwarfs give out most of their light in thermal infrared.

In fact, so difficult are they to spot, the first brown dwarf was not discovered until the late-Eighties, when astronomers Ben Zuckerman and Eric Becklin of the University of California, Los Angeles, found a suspected brown dwarf called GD 165B, although there remains some lingering doubt that it could just be a very low-mass star.

> "What we see here is evidence for massive, organised cloud systems akin to giant versions of the Great Red Spot on Jupiter" **Professor Adam Showman, University of Arizona**

Astronomers then had to wait another ten years before finding more brown dwarfs, with Teide 1 in the Pleiades star cluster being discovered in 1995. Of course, brown dwarfs had been theorised to exist long before the Eighties, and it was actually Jill Tarter of SETI fame who came up with the name 'brown dwarf' in 1975. Previously they had been known as black dwarfs, but this caused confusion with the other black dwarfs, which are what white dwarfs will eventually become when they cool down over trillions of years. Besides that, in actual fact brown dwarfs are not black, or even really brown – they are more of a magenta shade.

Huge advances in our understanding of brown dwarfs have been made in recent years, mainly thanks to WISE, which is NASA's Wide-field Infrared Survey Explorer satellite. WISE spent a whole year scanning the sky in mid-infrared light, wavelengths in which cool brown dwarfs should just pop into view. "The brown dwarfs jump out at you like big, fat, green emeralds," says WISE deputy project scientist, Amy Mainzer. They appear green in WISE's images because their temperatures are coded to false colours. WISE has proven itself as a prolific brown dwarf discoverer, and it has ended up finding the coolest brown dwarfs discovered so far. They are so cool, in fact, that astronomers have had to come up with a whole new classification for them.



Brown dwarfs have been found to have different layers or patches of material, such as hot grains of sand, liquid drops of iron as well as other exotic compounds, swirling around its atmosphere in windy storms as large as Earth itself

Stars are grouped into types dependent on their temperature and luminosity. The hottest, most luminous stars are termed O-types. Next are B-types, then A-types, then F-types, G-types (like the Sun), K-types and M-types, the latter of which are red dwarfs. But brown dwarfs are even cooler than red dwarfs, so new types were needed to describe them, namely L and T-types. In 2014 though, astronomers using WISE found a brown dwarf called W0855-0714, which was so cold that it had a temperature of between -48 to -13 degrees Celsius (-54.4 to 8.6 degrees Fahrenheit). This brown dwarf was described as Y-type, and a dozen or so more have subsequently been identified. Scientists have not even been able to rule out the possibility of one or more brown dwarfs lying closer to the Sun than the current nearest star, Proxima Centauri, which is 4.2 light years away.

Traditionally, brown dwarfs are described as being between 13 and 80 times the mass of Jupiter, but W0855-0714 comes in below that – weighing only as much as between three to ten Jupiters – showing how difficult it is to define what a brown dwarf is, at least based on its mass. It has been speculated that it could be an escaped planet but astronomers suspect it is more likely to be a brown dwarf, simply because there should be so many brown dwarfs that the odds are against it being a rogue planet.

"The thick clouds on this brown dwarf [ULAS J222711] are mostly made of mineral dust, like enstatite and corundum" **Federico Marocco, University of Hertfordshire**

Brown dwarfs may form like stars, but they look more like planets, to the extent that they even have weather and clouds. For example, one brown dwarf, called ULAS J222711, appeared redder than other normal brown dwarfs. Under further inspection, astronomers from the University of Hertfordshire found that it was clouds scattering sunlight that were giving ULAS J222711 its red hue, but these were certainly not clouds like the fluffy water-vapour versions we have in Earth's sky.

"The thick clouds on this particular brown dwarf are mostly made of mineral dust, like enstatite and corundum," says the University of Hertfordshire's Federico Marocco. "Not only have we been able to infer their presence, but we have also estimated the size of the dust grains in the clouds." These dust grains were calculated to be about 0.5 micrometres (0.5 millionths of a metre or 20 millionths of an inch) across. On another brown dwarf that we have already mentioned, W0855, there is also evidence for frozen clouds of sulphides and water-ice, while gases such as methane, hydrogen sulphide and ammonia are taken as a given. "If you could bottle up a gallon of a brown dwarf's atmosphere and bring it back to Earth, smelling it wouldn't kill you but it would stink pretty bad, like rotten eggs with a hint of ammonia," says Amy Mainzer.

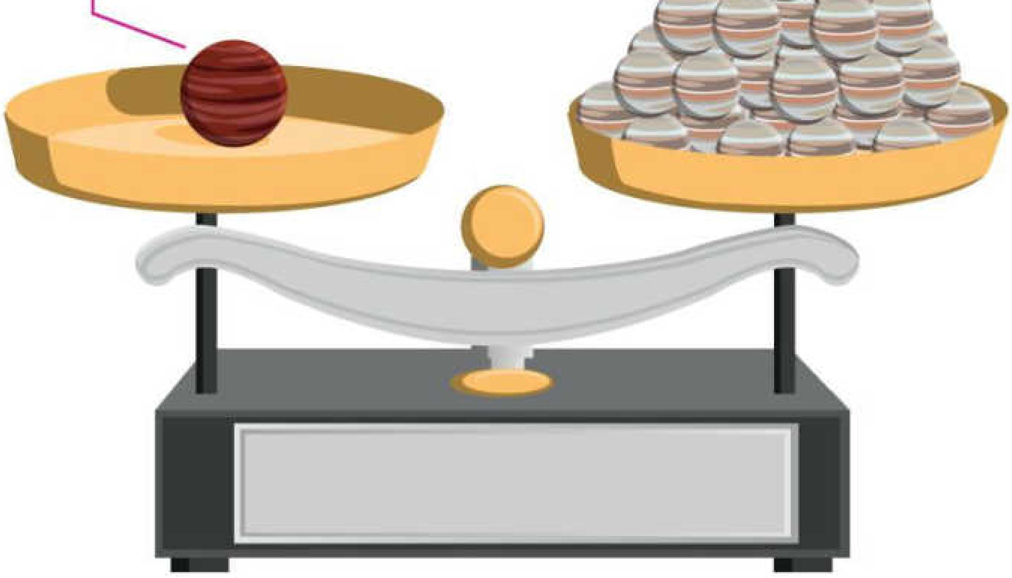
Most brown dwarfs could also be stormy, further cementing their similarities with Jupiter-like worlds. WISE's infrared predecessor, the still-operational Spitzer Space Telescope, has found signs of patchiness in the cloud cover of brown dwarfs, which could equate to roiling storm regions that sport terribly strong winds, enormous lightning strikes and rainfalls not of water, but of molten sand and iron. "What we see here is evidence for massive, organised

Teide 1: the first confirmed brown dwarf

Discovered in the Pleiades star cluster in the constellation of Taurus, Teide 1 was verified as a brown dwarf in 1995

Teide 1
Weighing in at a hefty 55 times the mass of Jupiter, Teide 1 has a temperature of around 2,327 degrees Celsius (4,220 degrees Fahrenheit) and is about 120 million years old.

55 Jupiters
Teide 1 might have a radius similar to that of gas giant Jupiter, but it takes 55 times the king of the Solar System to balance the scales.

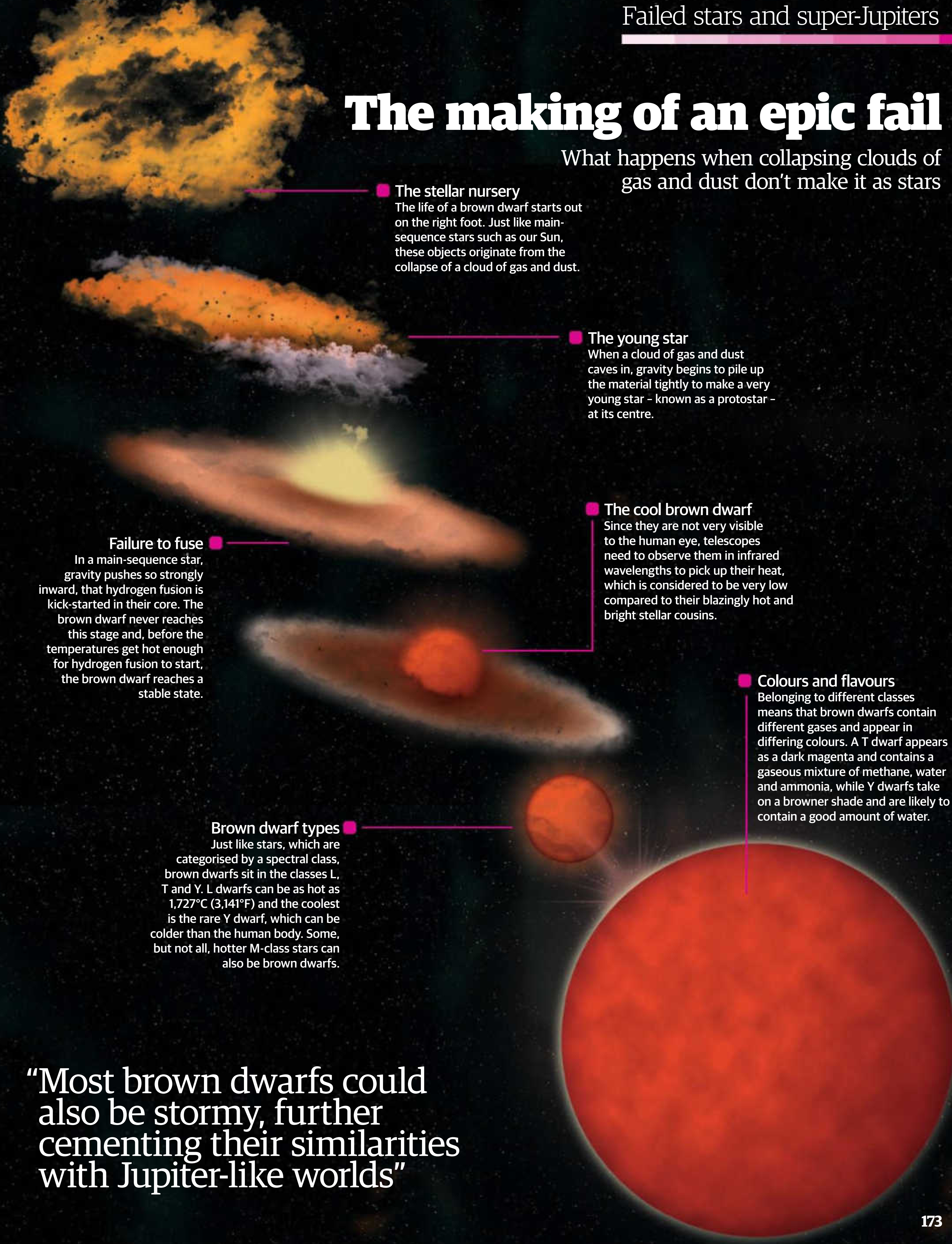


Brown dwarfs can be anything from 13 to around 80 times more massive than Jupiter

An infrared image of the Pleiades ('Seven Sisters') by the Spitzer Space Telescope

The making of an epic fail

What happens when collapsing clouds of gas and dust don't make it as stars



The stellar nursery

The life of a brown dwarf starts out on the right foot. Just like main-sequence stars such as our Sun, these objects originate from the collapse of a cloud of gas and dust.

The young star

When a cloud of gas and dust caves in, gravity begins to pile up the material tightly to make a very young star – known as a protostar – at its centre.

Failure to fuse

In a main-sequence star, gravity pushes so strongly inward, that hydrogen fusion is kick-started in their core. The brown dwarf never reaches this stage and, before the temperatures get hot enough for hydrogen fusion to start, the brown dwarf reaches a stable state.

The cool brown dwarf

Since they are not very visible to the human eye, telescopes need to observe them in infrared wavelengths to pick up their heat, which is considered to be very low compared to their blazingly hot and bright stellar cousins.

Colours and flavours

Belonging to different classes means that brown dwarfs contain different gases and appear in differing colours. A T dwarf appears as a dark magenta and contains a gaseous mixture of methane, water and ammonia, while Y dwarfs take on a browner shade and are likely to contain a good amount of water.

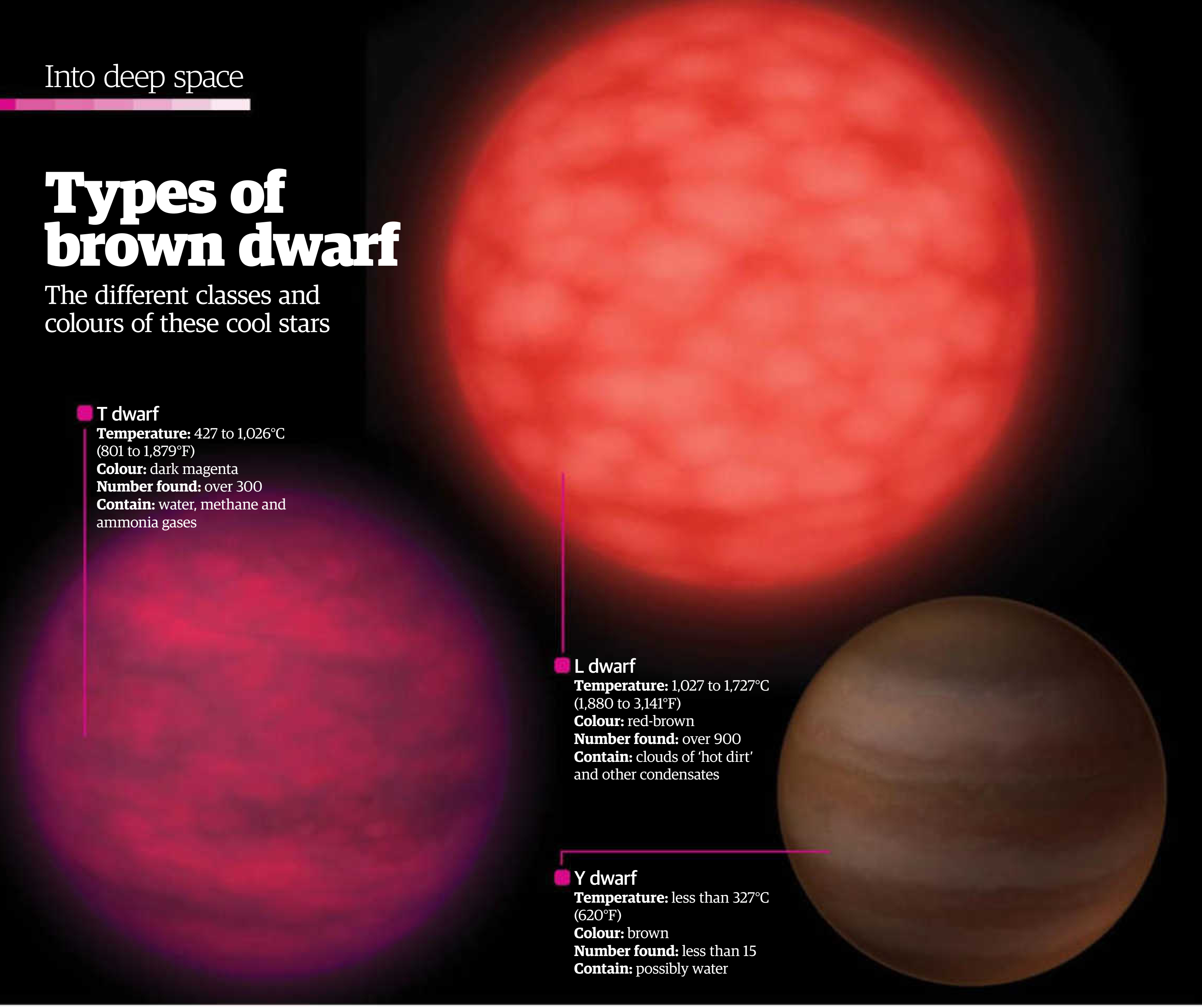
Brown dwarf types

Just like stars, which are categorised by a spectral class, brown dwarfs sit in the classes L, T and Y. L dwarfs can be as hot as 1,727°C (3,141°F) and the coolest is the rare Y dwarf, which can be colder than the human body. Some, but not all, hotter M-class stars can also be brown dwarfs.

"Most brown dwarfs could also be stormy, further cementing their similarities with Jupiter-like worlds"

Types of brown dwarf

The different classes and colours of these cool stars



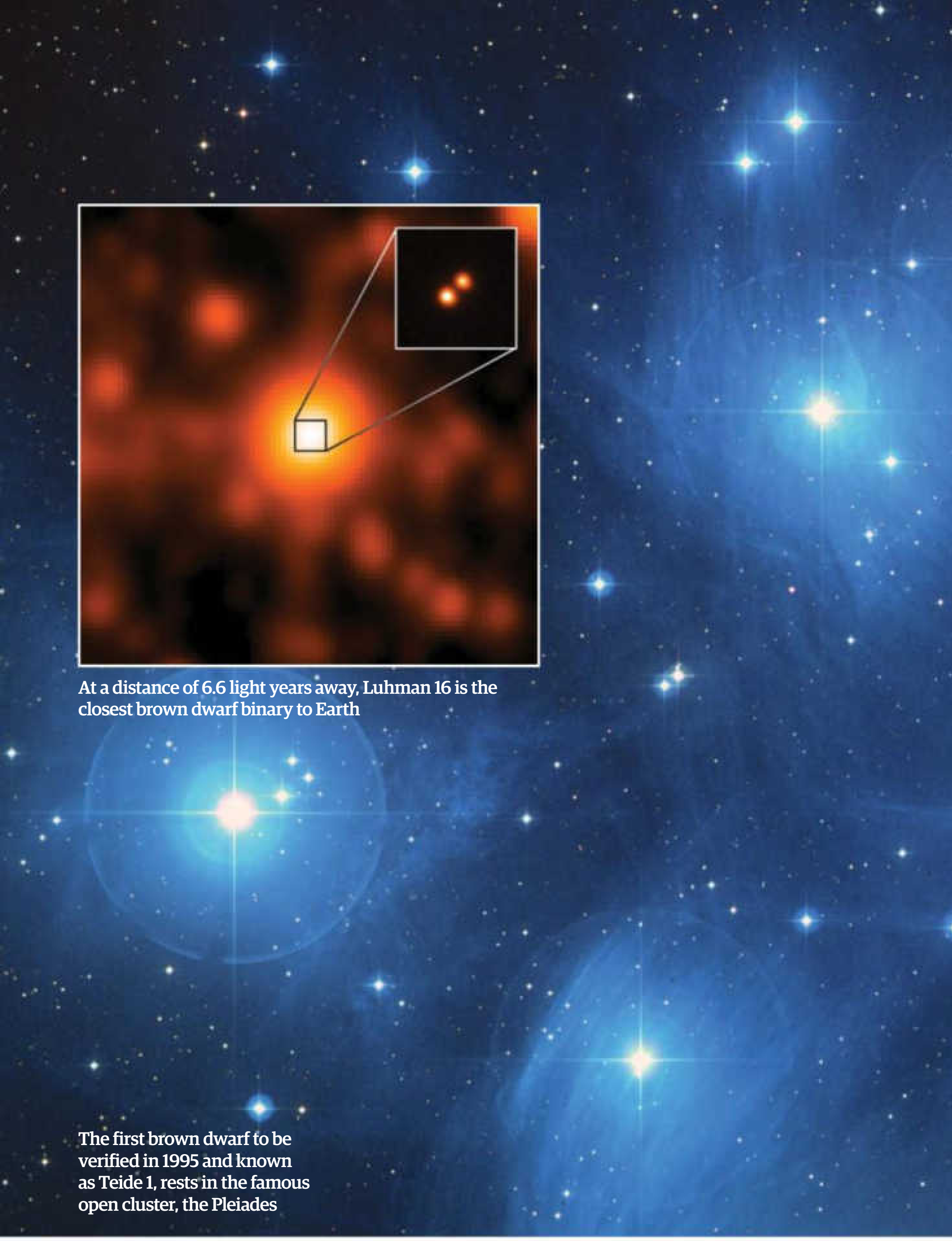
> "These out-of-sync light variations provide a fingerprint of how a brown dwarf's weather systems stack up vertically"

Professor Adam Showman, University of Arizona

cloud systems, perhaps akin to giant versions of the Great Red Spot on Jupiter," says Professor Adam Showman of the University of Arizona.

By teaming up Spitzer with Hubble, astronomers are able to look at brown dwarfs in different wavelengths of infrared light, which are able to peer down into different layers of a brown dwarf's atmosphere. As the brown dwarf rotates, variations in the amount of cloud cover and the size of the storms affects the brightness that Hubble and Spitzer space telescopes see. "These out-of-sync light variations provide a fingerprint of how a brown dwarf's weather systems stack up vertically. The data suggests regions on a brown dwarf where the weather is cloudy and rich in silicate vapour deep in the atmosphere coincide with balmier, drier conditions at higher altitudes – and vice versa," says Showman.

But where do brown dwarfs get the energy from to drive weather and planet-sized storms? On Earth, the energy for our weather systems comes from heat emitted by the Sun. Certainly, some brown dwarfs are found orbiting stars, but that does not explain where brown dwarfs without stellar companions get their heat from. A world like Jupiter, which is far from the Sun, still retains some residual heat within its core from the days when it was formed, and some of the heat of brown dwarfs will come from the same source. However, brown dwarfs have an advantage over worlds like Jupiter. Although they are lacking too much mass to ever have the required pressures



At a distance of 6.6 light years away, Luhman 16 is the closest brown dwarf binary to Earth

The first brown dwarf to be verified in 1995 and known as Teide 1, rests in the famous open cluster, the Pleiades

Brown dwarf discovery

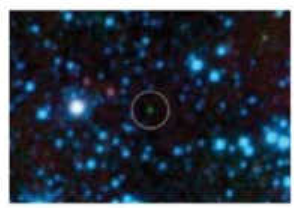
NASA's WISE telescope is an expert when it comes to hunting down brown dwarfs

2011: The spacecraft confirms the existence of a new class of brown dwarf known as the Y dwarf. These brown dwarfs can have temperatures as cool as the human body.

2013: The discovery of the closest brown dwarfs to Earth is announced. They were discovered using WISE at a distance of 6.6 light years away, and are locked in a binary system called Luhman 16.

2014: WISE finds the coldest known brown dwarf, which has an ultra-cool temperature between -48 and -13 degrees Celsius (-54.4 and 8.6 degrees Fahrenheit).

2015: NASA's WISE mission has discovered over 200 brown dwarfs to date.



Discovered in 2011, WISE 0458+6434 was the first ultra-cool brown dwarf found by NASA's space telescope

and temperatures in their cores to instigate nuclear fusion of hydrogen into helium, they can for a short while ignite nuclear fusion reactions of deuterium. The most massive brown dwarfs are also able to fuse lithium – lithium does not exist in any significant quantities in normal stars, so a search for lithium is a good test of whether an object is a brown dwarf or not. The smallest brown dwarfs that are less than 13 times the mass of Jupiter are not hot enough in their cores for any fusion reactions. Nevertheless, those that are able to start the reactions can, for a short while, produce heat and energy this way, which resides in the star for billions of years after the fusion reactions have actually run themselves out.

Inside a star like the Sun, there are two zones. The innermost is the radiative layer around the nuclear core, where energy produced by fusion reactions is transported through radiation. It is this energy that holds the Sun up against the pull of its gravity. Above the radiative layer is the convective layer, where convection currents transport the rest of the way to the Sun's surface. Brown dwarfs, however, are suspected to only have convective layers. This leads to their interiors being 'springy', so they can become more compressed with greater mass. This results in brown dwarfs that, astonishingly, are not much larger than the diameter of Jupiter, despite some having dozens of times more mass.

This could result in the surprising scenario where a planet orbiting a brown dwarf is actually bigger than the brown dwarf! Given that brown dwarfs are not proper stars, it had been uncertain as to whether planets could form around them. However, the Atacama Large Millimeter/submillimeter Array (ALMA), in the Chilean desert, has discovered a disc of dust and rubble around a brown dwarf, just like the planet-forming dust discs that astronomers find around young stars. The disc around the brown dwarf, which is known as ISO-Oph 102 and which has 60 times the mass of Jupiter, contains millimetre-sized dust grains. In the planet-forming discs around young stars, these grains gradually begin to stick together, growing larger and larger until they build up into rocky planets.

"We were completely surprised to find millimetre-sized grains in this thin little disc," says Luca Ricci, from the California Institute of Technology in Pasadena, who headed the team of astronomers who used ALMA to find this disc. "Solid grains of that size shouldn't be able to form in the cold outer regions of a disc around a brown dwarf, but it appears that they do. We can't be sure if a whole rocky planet could develop there, or already has, but we're seeing the first steps."

This leaves brown dwarfs facing something of an identity crisis. They form in the same way as stars but are not stars, unable to fuse hydrogen into helium. They look like planets with weather systems but are more massive and don't form like planets, yet they may be able to form proper planets orbiting around them. They are also likely the most common type of object in the universe – some scientists even suspect that there could be enough unknown brown dwarfs to account for some of the missing mass that has been attributed to dark matter. Yet despite all of this they will always be seen as failures, objects that couldn't make the grade to become stars, when really we should see them as super-planets that take on some star-like qualities. The brown dwarf is truly a unique breed of object, capable of taking on the role of both planet and star, while possibly revealing more about our hidden universe.

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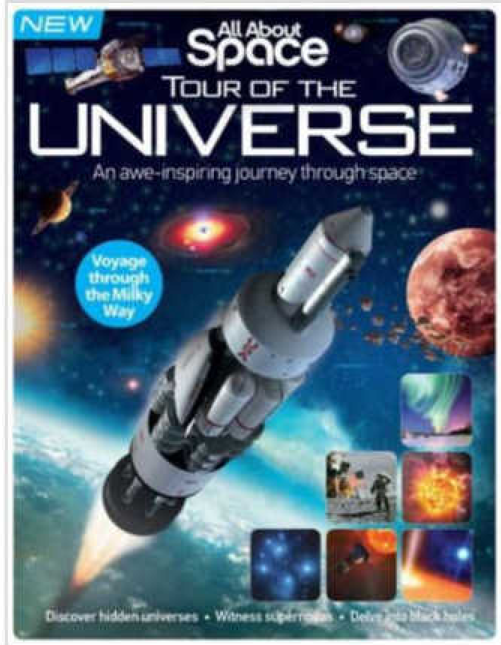

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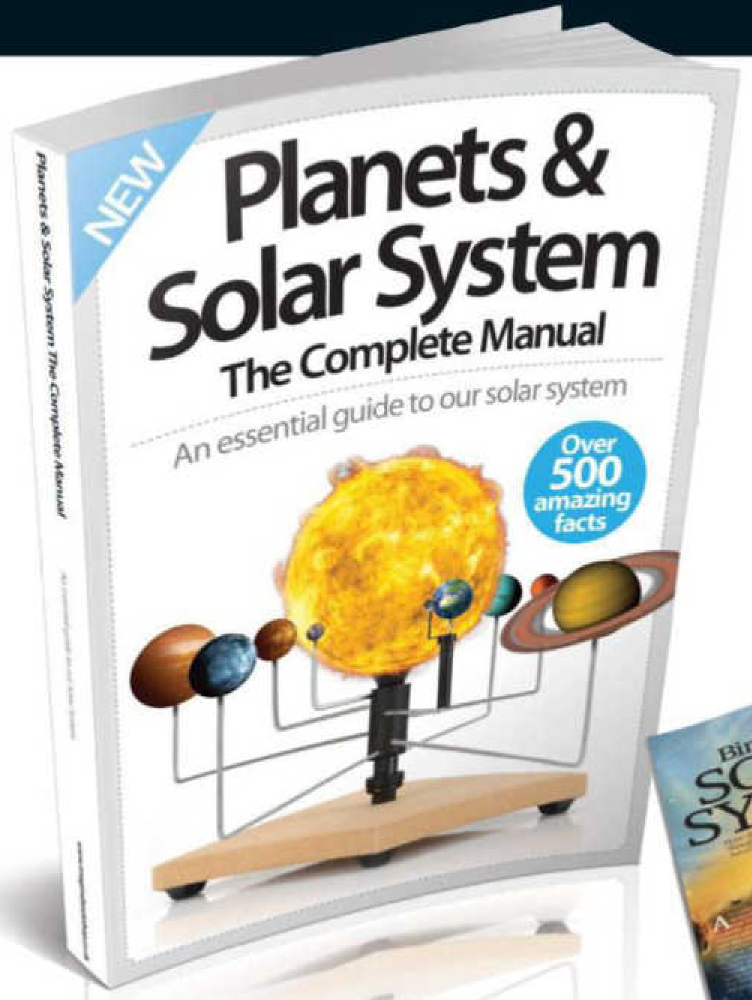

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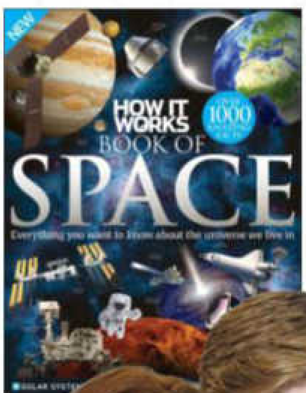

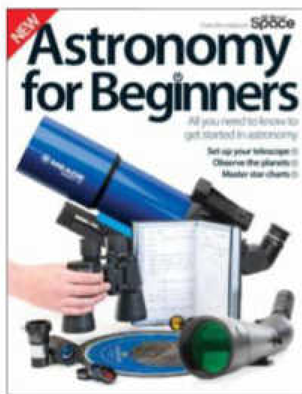

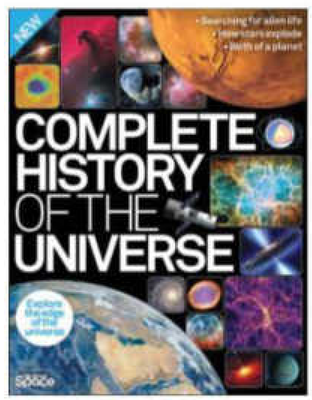

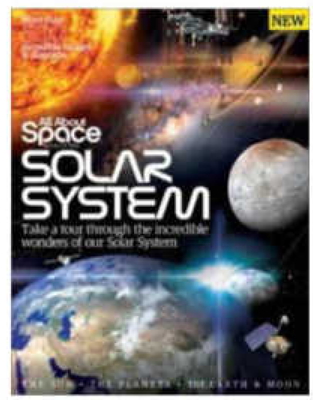

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